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AN IMPROVED METHOD OF DETERMINING SHOCK TEST SPECIFICATIONS FOR FIRE CONTROL EQUIPMENT

By

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June 1976

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19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Shock	Fire Control Instruments	Laboratory Simulation
Shock Test	Mortar, M29	Specification Fire Control
Shock Spectrum	Howitzer, M102	Firing Transients
Shock Specification	Sheridan Vehicle, M551	

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This program was conducted to improve the procedure for developing and executing specification laboratory shock tests of production type fire control instruments (FC). Many laboratory tests were conducted using FC of M29 Mortar, M102 Howitzer, and M551 Sheridan Vehicle, since on a structural dynamics basis these instruments represent most FC Groups. For various g levels and impulse times, each instrument's resulting laboratory shock test spectra from each combination of location and direction were compared to composite field spectra from that same combination for correlation.

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20. ABSTRACT (Cont)

Reported here is a recommended selection of proper g levels with corresponding impulse times which produce adequate laboratory simulation of field results without severe over (or under) - testing or erroneous, laboratory induced failure. Additional benefits are : 1) a reduction in present number of specified shock tests without significant information loss, 2) good simulation of field results using standard commercially available shock machines, 3) substantial cost reduction via less complex test procedure and simpler fixturing.

These reported Frankford Arsenal test procedures are recommended for incorporation with various FC specifications. Furthermore, for increased efficiency, it is recommended that the type of test validation procedure described be conducted as a follow-on activity to field shock data acquisition programs.

TABLE OF CONTENTS

		Page
Section 1	INTRODUCTION	1
Section 2	M29 81MM MORTAR	6
Section 3	M102 105MM TOWED LIGHT HOWITZER	24
Section 4	M551 SHERIDAN VEHICLE	54
Section 5	DEVELOPING A SHOCK TEST TO SIMULATE THE EFFECTS OF FIRING MANY ROUNDS	71
Section 6	CONCLUSIONS AND RECOMMENDATIONS	73
	REFERENCES	77
	DISTRIBUTION	78

LIST OF ILLUSTRATIONS

Figure No.		Page
1	Instrumented M29 Mortar's M53 Sightunit Mounted for a Positive Vertical Shock.	7
2	Vibration Response of the M29 Mortar's M128 Telescope Mount in the Vertical Direction.	8
3	Vibration Response of the M29 Mortar's M109 Elbow Telescope in the Transverse Direction.	8
4	Acceleration Time Histories of the M29 Mortar's M53 Sightunit.	10
5	Acceleration Time Histories of the M29 Mortar at the Bottom of the Mortar Tube.	10
6	Primary Shock Response Spectrum of the M29 Mortar's M53 Sightunit in the Vertical Direction. Firing Conditions: Standard Round at 800 mils Elevation.	11

Figure No.		Page
7	Primary Shock Response Spectrum of the M29 Mortar's M53 Sightunit in the Longitudinal Direction. Firing Conditions: Standard Round at 800 mils Elevation.	11
8	Primary Shock Response Spectrum of the M29 Mortar's M53 Sightunit in the Transverse Direction. Firing Conditions: Standard Round at 800 mils Elevation.	12
9	Primary Shock Response Spectrum of the M29 at the Bottom of the Mortar Tube in the Bore Direction. Firing Conditions: Standard Round at 1400 mils Elevation.	12
10	Acceleration Time Histories of the M29 Mortar's M53 Sightunit due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.	14
11	Acceleration Time Histories of the M29 Mortar's Sightunit due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Aft) Direction.	15
12	Primary Shock Response Spectrum of the M29 Mortar's M128 Telescope Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.	16
13	Primary Shock Response Spectrum of the M29 Mortar's Telescope Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Aft) Direction.	16
14	Primary Shock Response Spectrum of the M29 Mortar's M128 Telescope Mount in the Transverse Direction to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.	17
15	Primary Shock Response Spectrum of the M29 Mortar's M128 Telescope Mount in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.	17

Figure No.		Page
16	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope in the Vertical Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.	19
17	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope in the Longitudinal Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.	19
18	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope in the Transverse Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.	20
19	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Vertical Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Vertical Plain at 45° to the Longitudinal Axis.	20
20	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Longitudinal Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Vertical Plain at 45° to the Longitudinal Axis.	22
21	Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Transverse Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.	22
22	M102, 105MM Towed Light Howitzer.	25
23	Front View of the M102 Howitzer's M14 Quadrant and M114 Elbow Telescope Mounted for a Positive Vertical Shock.	26

Figure No.		Page
24	Side View of the M102 Howitzer's M14 Quadrant and M114 Elbow Telescope Mounted for a Positive Vertical Shock.	26
25	Sketch of the Accelerometer Locations on the M102 Howitzer's M14 Quadrant and M114 Elbow Telescope.	27
26	Vibration Response of the M102 Howitzer's M114 Telescope in the Transverse Direction, (Position 23).	27
27	Vibration Response of the M102 Howitzer's M114 Elbow Telescope in the Longitudinal Direction, (Position 21).	28
28	Vibration Response of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 11).	28
29	Acceleration Time Histories of the M102 Howitzer, at the M14 Quadrant and M114 Elbow Telescope. Firing Conditions: Excess Charge and 400 mils Elevation.	30
30	Acceleration Time Histories of the M102 Howitzer, at the M14 Quadrant. Firing Conditions: Excess Charge and 400 mils Elevation.	31
31	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Vertical Direction, (Position 17).	33
32	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 10).	33
33	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Transverse Direction, (Position 15).	34

Figure No.		Page
34	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Vertical Direction, (Position 18).	34
35	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 11).	35
36	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 12).	35
37	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Transverse Direction, (Position 16).	36
38	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Vertical Direction, (Position 22).	36
39	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Longitudinal Direction, (Position 21).	37
40	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Transverse Direction, (Position 23).	37
41	Indirect Fire Control System of the M102 Howitzer, Comprised of the Telescope Mount M134 and the Panoramic Telescope M113.	39
42	Indirect Fire Control Mounted for a Positive Vertical Shock on the LAB Shock Machine, Showing the Accelerometer Locations.	40

Figure No.		Page
43	Vibration Response at the Base of the M102 Howitzer's M134 Mount in the Trunnion Direction.	43
44	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Horizontal Fore and Aft Direction, (Position 1).	43
45	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Trunnion Direction, (Position 2).	44
46	Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Vertical Direction, (Position 3).	44
47	Comparison of Field and Recommended Laboratory Shock Response Spectra at the Middle of the M102 Howitzer's M134 Telescope Mount in the Horizontal Fore and Aft Direction, (Position 4).	45
48	Comparison of Field and Recommended Laboratory Shock Response Spectra at the Top of the M102 Howitzer's M134 Telescope Mount in the Trunnion Direction, (Position 6).	45
49	Comparison of Field and Recommended Laboratory Shock Response Spectra at the Base of the M102 Howitzer's M134 Telescope Mount in the Trunnion Direction, (Position 7).	46
50	Comparison of Field and Recommended Laboratory Shock Response Spectra at the Top of the M102 Howitzer's M134 Telescope Mount in the Vertical Direction, (Position 8).	46
51	Comparison of Field and Recommended Laboratory Shock Response Spectra at the Base of the M102 Howitzer's M134 Telescope Mount in the Horizontal Fore and Aft Direction, (Position 9).	47

Figure No.		Page
52	Acceleration Time Histories of the M102 Howitzer's Indirect Fire Control due to Field Firing Test (Round 18). Firing Conditions: Excess Charge and 400 mils Elevation.	48
53	Acceleration Time Histories of the M102 Howitzer's Indirect Fire Control due to Laboratory Drop Test 16. Test Conditions: 50 g, 2 Milliseconds in the Vertical Upward Direction on the LAB Shock Machine.	49
54	M551 Sheridan Vehicle and Optical Fire Control Instruments.	55
55	Laboratory Accelerometer Locations on the M551 Sheridan's M127 Telescope, its M149 Mount, and its Fixture.	56
56	Positioning of the M551 Sheridan's M127 Telescope, M149 Mount, and Fixture on the LAB Shock Machine.	57
57	Typical Field Acceleration Time Histories Measured on the M551 Sheridan's M127 Telescope and M149 Mount. Firing Conditions: Main Gun Firing Conventional Ammunition, Facing Forward at 20° Elevation.	58
58	Typical Laboratory Acceleration Time Histories of the M551 Sheridan's M127 Telescope and M149 Mount due to a 150 g, 1 Millisecond Positive Vertical Shock.	59
59	Vibration Response of the M551 Sheridan's M149 Mount in the Vertical Direction.	61
60	Vibration Response of the M551 Sheridan's M149 Mount in the Transverse Direction.	61
61	Vibration Response of the M551 Sheridan's M149 Mount in the Longitudinal Direction.	62

Figure No.		Page
62	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M127 Telescope in the Vertical Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Vertical Direction.	63
63	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Vertical Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Vertical Direction.	63
64	Comparison of Field and Laboratory Shock Response of the M551 Sheridan's M127 Telescope in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.	64
65	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.	64
66	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M127 Telescope in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.	65
67	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.	65
68	The M551 Sheridan's XM44 Periscope Mounted on the Avco Shock Machine Positioned for a Positive Longitudinal Shock.	67

Figure No.		Page
69	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Vertical Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Vertical Direction.	68
70	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Vertical Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Vertical Direction.	68
71	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Transverse Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Transverse Direction.	69
72	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Transverse Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Transverse Direction.	69
73	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Longitudinal Direction due to a 50 g, 3 Millisecond Half-Sine in the Longitudinal Direction.	70
74	Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Longitudinal Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Longitudinal Direction.	70

LIST OF TABLES

Table No.		Page
I	Resonant Transmissibility from Sine Sweep Vibration Testing of the M102 Howitzer's Indirect Fire Control.	42
II	Summary of Half-Sine Drop Tests for the M102 Howitzer's Indirect Fire Control.	50
III	Comparison of Field and Laboratory Shock Response Spectra of the M102 Howitzer's Indirect Fire Control using the Maximum of the Primary Positive and Negative Spectra for Q = 10.	52
IV	Recommended Shock Tests.	75

Section 1

INTRODUCTION

For many years, Frankford Arsenal has been involved in the development and production of fire control instruments for most of the Army's weapon systems. These instruments range from simple sighting devices for small arms weapons, to complex integrated systems such as in the M551 Sheridan Vehicle. One of the most severe environments the equipment is subjected to is the high intensity shock resulting from firing of the weapon. The fire control instruments must not only survive this shock, but must function and retain boresight within extremely close tolerances.

Laboratory shock tests are performed on fire control instruments, both in the development and production phases, to insure that they will perform satisfactorily in field use. Whenever possible, field firing shock measurements are made early in the life cycle of an instrument. The data is analyzed, laboratory shock tests are developed based on the data, and laboratory tests are performed in order to identify design weaknesses prior to production. Once the equipment is in production, the shock test becomes part of the quality assurance provisions, and is performed to insure that the equipment, as produced, is satisfactory. In lieu of field data, shock tests are prescribed based on similarity to existing systems, or are drawn from a major environmental specification such as MIL-STD-810C.[1]

The process described seems reasonable enough, but after assessing the laboratory results over many years and many tests, one would have to admit that something is lost between acquiring field data and specifying a suitable laboratory test. Too often, laboratory test failures are generated in items with a satisfactory history of field performance. In addition, tests of an instrument which are being performed because of a troublesome component, result in failures unrelated to the investigation. Occurrences such as these are not frequent, but they occur often enough to limit our confidence in laboratory shock testing. The tests are necessary, and a vital part of the process of insuring reliable equipment, but there is a need to improve the degree of simulation achieved in laboratory shock testing.

The program described in this report was undertaken in an effort to develop improved shock test methods in the laboratory testing of production fire control instruments. The aim was to improve the procedures used in developing and conducting laboratory shock tests in order to achieve greater correlation between field and laboratory results. With improved shock test methods and greater confidence in laboratory results, requirements for field firing programs could be reduced. Substantial long term cost savings could be realized if the program leads to reduced testing requirements or to simplification in the fixturing or test procedures. This could also result in reduced laboratory test schedules.

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[1]Military Standard 810 C, "Environmental Test Methods", 10 Mar. 75.

Discussion of Current Test Selection Procedures

Generally, the indications from present laboratory shock test results are that the tests tend to be overly severe. While it is certainly better to overtest in the laboratory, rather than undertest and risk faulty equipment, the degree of overtest should not be extreme. The process of selecting a shock test to simulate the field environment should be conservative, but not to the extent of generating unrealistic failures. The initial phase of the present program, was to assess the process typically used in specifying and conducting laboratory shock tests. This would help identify those aspects of the process that are unduly conservative, or perhaps are altogether deficient. With a knowledge of potential problem areas, a program could be formulated to investigate and evaluate these problem areas, and should lead ultimately to improved test procedures.

In developing a laboratory shock test, the first step is to obtain field firing data on the equipment for a variety of typical firing conditions. The data is usually analyzed in the form of a maximax shock spectrum, assuming little or no damping, and the resulting spectra are compared with those for simple laboratory shock pulses such as half-sines or sawtooth pulses. The laboratory pulses whose spectra best compare with the field spectra, are then selected to be applied in the three major axes of the instrument. Following the procedures of MIL-STD-810C,[1] the pulses are applied three times in each direction of each axis for a total of eighteen shocks. Normally, the concern is to specify the shock input to an instrument corresponding to the measurements obtained at the point where the instrument is mounted on the weapon. The response of the instrument to the laboratory shock at points other than the mounting area is usually not monitored, since the emphasis in laboratory testing is on specifying the input to the test item.

There are several aspects of the test selection procedure which appear to be conservative. Enveloping of the maximax shock spectra with the laboratory spectra is conservative since it is concerned with the peaks and ignores the valleys in the spectra. This could lead to severe overtesting. The assumption of little or no damping in the structure is also conservative. It results in maximum values of the shock spectra when actual instruments, with some damping, will not respond to this extent. The typical fire control instrument consists of sections bolted together with gaskets between them and a myriad of prisms, mirrors, shafts, gears and bearings. Such structures do exhibit some damping when vibrated, and will not usually respond at resonance with the high amplification factors typical of lightly damped structures.

The practice of applying shock excitation in both directions of each axis may be conservative and should be explored. Firing of a weapon produces a fairly clean unidirectional shock pulse acting on the breech of the gun. The pulse causes vibratory responses throughout the structure of the weapon, and ultimately the input to the fire control instrument is a complex, multidirectional transient vibration. When

[1]Military Standard 810 C, "Environmental Test Methods", 10 Mar. 75.

looking at firing shock data on an instrument, the actual firing direction is usually not obvious. Fire control instruments typically have complex shapes, and it is probable that a shock applied in one axis of the instrument will generate not only positive and negative responses along that axis, but in other axes as well.

It is clear from this discussion that several practices used in selecting shock tests for fire control are conservative and could lead to overtesting and unnecessary failures. The most glaring weakness in the process, however, would seem to be that the test item is not ordinarily monitored in the laboratory as it was in the field, to insure that similar responses are being generated. Since the test items are complex, often non-linear, and not single-degree-of-freedom systems, perhaps the responses in the laboratory are not the same as those in the field, even if the inputs are similar in terms of their shock spectra. Validating, or testing, the test procedure appears then to be a necessary, if not crucial, step in developing laboratory shock test procedures that correlate well with the field environment.

Development of the Test Program

The preceding discussion identifies some of the conservative aspects in the process of specifying laboratory shock tests, and indicates a need to verify the suitability of the tests. A laboratory test and measurement program was formulated to evaluate the various problem areas in specifying laboratory tests, and assess the degree of simulation achieved. The test program developed was as follows:

1. Vibrate the fire control instrument, monitoring it at the same points monitored in the field test, and determine approximate damping values and critical frequencies.

2. Analyze the firing shock data in the form of maximax shock spectra for both minimum damping, and for a value of damping, suitable for the instruments. In addition, analyze the data in the form of primary (+) and primary (−) shock spectra in order to investigate the directional properties of the field environment.

3. Select a tentative shock test procedure by comparing the shock spectra for simple laboratory pulses to those obtained in the field measurements at the equipment mounting points.

4. Perform the proposed shock test in the laboratory, monitoring the same response points as in the field firing program. Analyze the laboratory data in the form of shock spectra, in the same manner as was done with the field data.

5. Compare field and laboratory response spectra for the various monitoring points, and determine suitable changes in the test parameters to improve the degree of simulation.

6. Repeat the "test and compare" process until acceptable correlation between the field and laboratory shock environments is achieved.

The guidelines used in selecting the shock test procedures were determined by the fact that the program is concerned with production fire control instruments. Therefore, test procedures should be as simple and economical as possible, while being repeatable and providing an acceptable degree of simulation. The intent of the process is to provide a good simulation rather than a duplication of the field environment. Duplication would be extremely difficult, if not impossible, expensive, and not suitable for in-process testing. It is also desirable that commercial shock machines be used in testing because of their wide availability. Half-sine shock machine pulses should be used whenever possible because they can be easily generated with reusable elastic impact pads. Tuned fixtures or exotic shock generating methods should be used only if standard shock test procedures prove to be unacceptable. The thrust of this program is to use commercial equipment and standard shock test methods if at all possible.

The program outlined above should result in improved laboratory test procedures which will eliminate the occurance of unrealistic failure during laboratory testing. To gain as much information as possible and gain confidence in the process, the test program should be applied to a wide range of typical fire control instruments. From a structural point of view, fire control instruments for artillery weapons tend to be similar, as do tank periscopes and telescopes, and mortar sights. Each of these represents a distinct class of instruments. It was therefore desirable that the program include samples from these three major types of fire control systems. A prerequisite, of course, was that firing shock data would have to be already available for any systems used in the program. The following systems and instruments were selected for inclusion in the test program.

Mortar System (M29 81MM Mortar)
Fire Control Instrument:
M53 Sightunit
M128 Telescope Mount
M109 Elbow Telescope

Artillery System (M102 105MM Howitzer)
Direct Fire Control System:
M14 Quadrant
M114 Elbow Telescope

Indirect Fire Control System:
- M134 Telescope Mount
- M113 Panoramic Telescope

Tank System (M551 Sheridan Vehicle)
Fire Control Instruments:
- M127 Telescope
- M149 Telescope Mount
- XM44 Periscope

Because of its small size and minimum number of data channels, the M53 Sight-unit was selected as the first instrument to be studied in the test and measurement program. It was thought that the sequence would go faster with this unit than for the larger, more complex instruments, therefore the program could be evaluated quickly to determine if it should be modified. The remainder of the report describes the laboratory shock test program conducted on the selected instruments and recommends an improved shock test procedure.

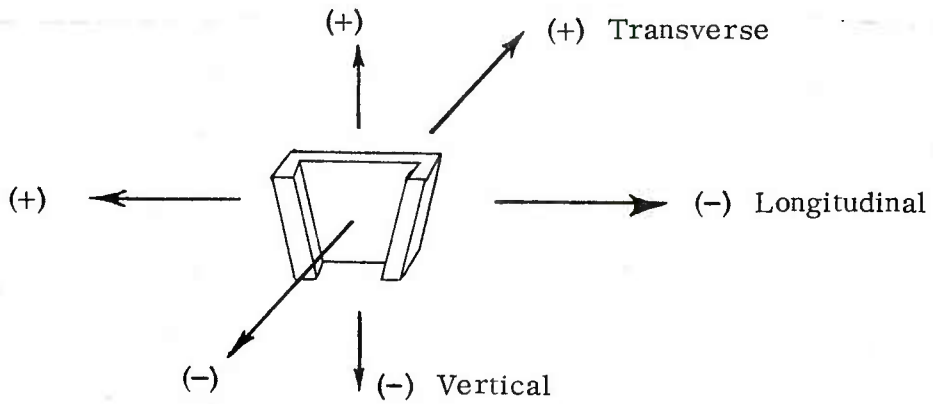
Section 2

M29 81MM MORTAR

The M29 Mortar is a smooth bore, muzzle loading weapon consisting of the following three main units: the Barrel, Mount and Baseplate. The fire control is a Sightunit (M53), which comprises an Elbow Telescope (M109) and its Mount (M128).

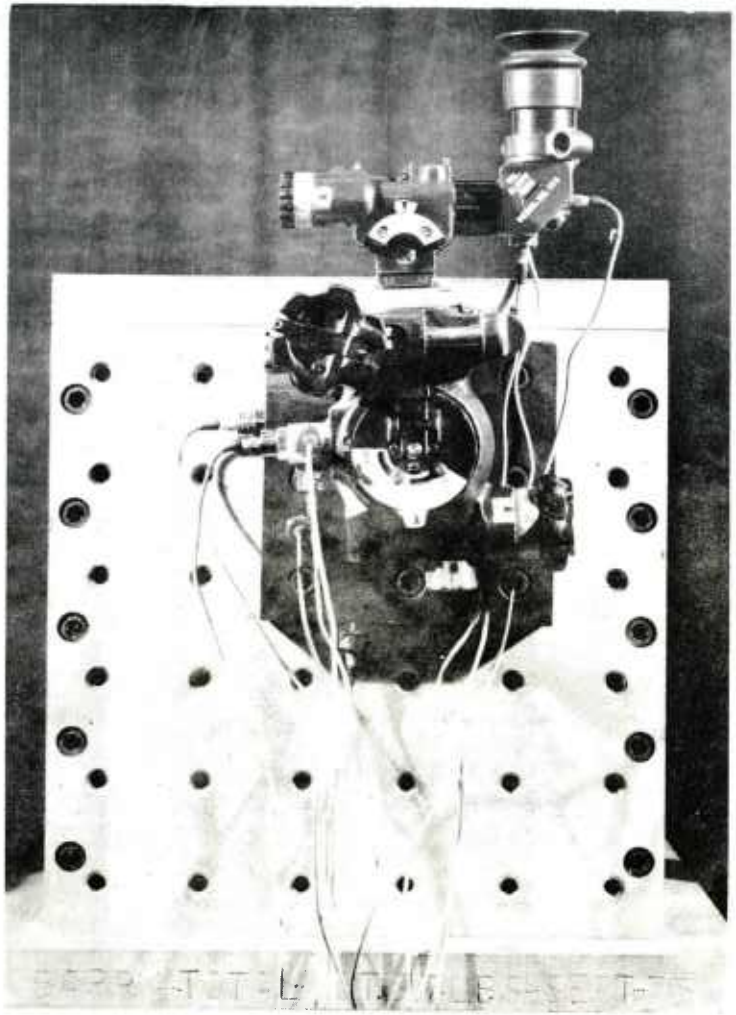
Laboratory Testing and Results

The M53 Sightunit was first vibrated in the laboratory in order to determine its frequency response characteristics and approximate damping ratios. A steel plate incorporating a dovetail was used to mount the Sightunit, and three accelerometers were mounted at each of the following three locations: on the M109 Elbow Telescope, on the M128 Telescope Mount, and on the mounting plate as shown in Figure 1. Field data on the Sightunit[2] was obtained only on the Telescope Mount, and so the responses at this position were the only ones that could be used in evaluating the laboratory shock tests. The Elbow Telescope position was also monitored throughout the program in order to more completely show the effect of the laboratory shock. Using a vibration input level of ±1/2 g, the Sightunit was vibrated in each of three mutually perpendicular axes over a frequency range of 10-500 Hertz, and X-Y plots of transmissibility vs the frequency response were obtained at each of the six accelerometer locations. The axes were identified using the dovetail as a reference, as shown below.

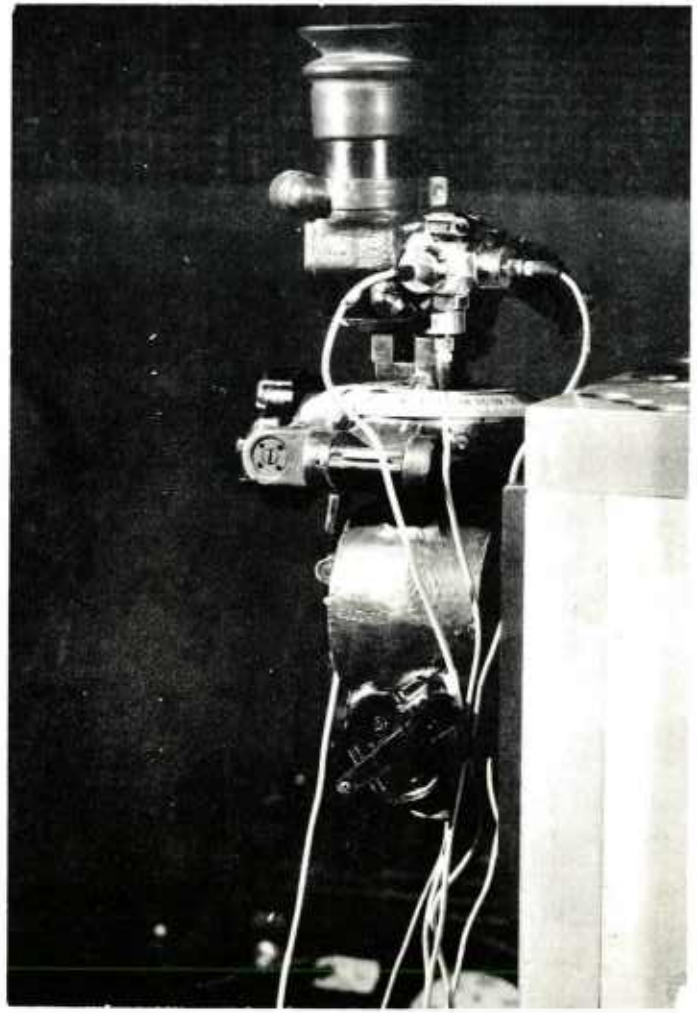


The Frequency response curves at two accelerometer locations are shown in Figures 2 and 3. Figure 2 is a representative curve of a stiff system with

[2]Holland, R.S. and Marcus, D., "Laboratory Shock Specifications for the Fire Control of the M110, M109 and M102 Howitzers and the M29 Mortar, Derived from Field Firing Tests," Frankford Arsenal Report R-3014, June 1974.



Front View



Side View

Figure 1. Instrumented M29 Mortar's M53 Sightunit Mounted for a Positive Vertical Shock.

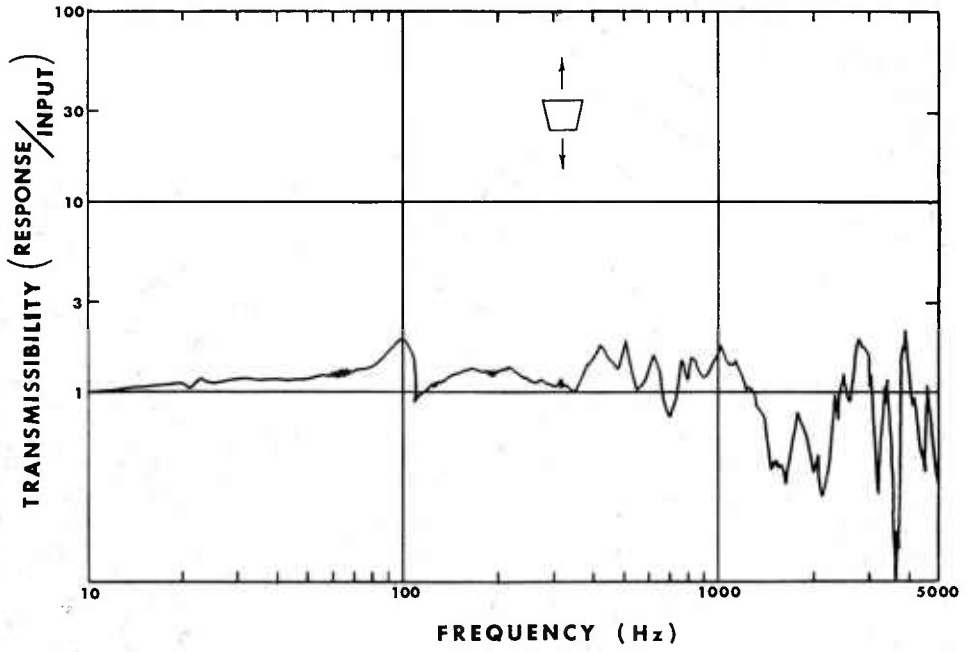


Figure 2. Vibration Response of the M29 Mortar's M128 Telescope Mount in the Vertical Direction.

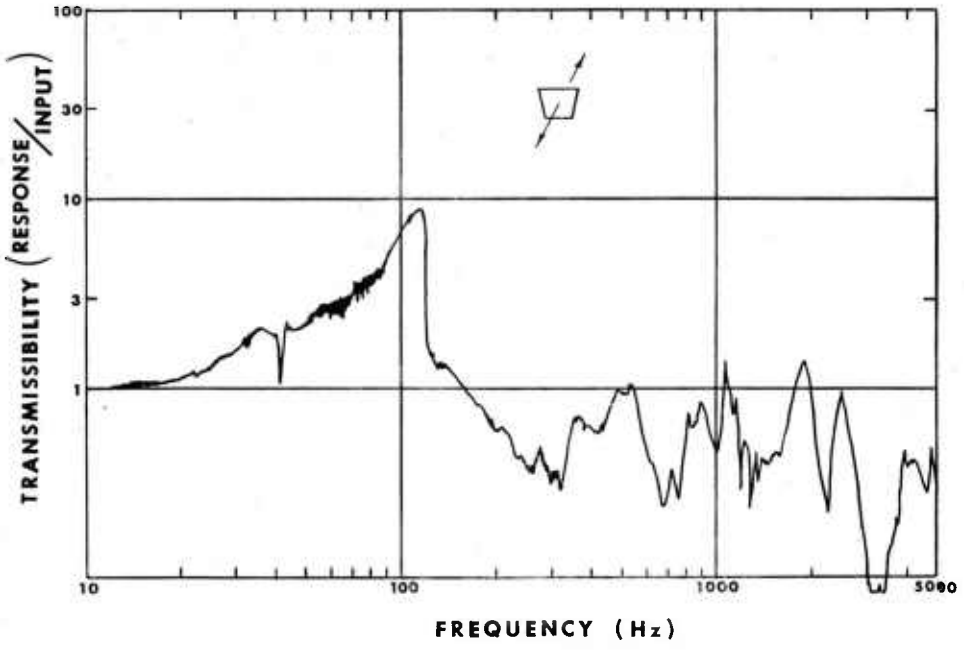


Figure 3. Vibration Response of the M29 Mortar's M109 Elbow Telescope in the Transverse Direction.

no major resonances. As seen in this figure the transmissibility, which is the amplification of the input, is less than 3. The Telescope Mount is also stiff in the longitudinal direction, and its transmissibility curve has similar characteristics. Figure 3 is a representative curve for a system with a resonant frequency. This figure shows the Elbow Telescope to have a 115 Hertz resonance in the transverse direction with a transmissibility just less than 10. In the longitudinal direction the Elbow Telescope has a resonance at 66 Hertz and a transmissibility of 4. In the vertical direction the Elbow Telescope is very stiff and has a transmissibility curve similar to that of the Telescope Mount. Since the transmissibility "Q" of the system was less than 10 for all components and all directions, a value of 10 was selected for the shock spectrum analysis. The higher value of Q, the more severe the spectrum will be and therefore a value of 10 is considered to be conservative. The value of damping that corresponds to a Q of 10 is .05 or 5%. The equation relating the damping to the Q is as follows:

$$\text{Damping} = \frac{1}{2Q}$$

Field firing shock data was available on the M29 Mortar, the measurements being obtained on the Telescope Mount as previously mentioned, and on the Mortar Tube near the Baseplate. The taped data was analyzed in terms of maximax shock spectra for damping ratios of 0.5% (minimum value) and 5%, and in terms of primary shock spectra, (+) and (-), for 5% damping and a 1 second period. The analyzer used was a Spectral Dynamics Model SD 320 Shock Spectrum Analyzer which provided an analysis over the range from 10-10,000 Hertz. Round 7, a standard round fired at an elevation of 800 mils, resulted in the highest shock spectrum levels over much of the frequency range for the three Telescope Mount channels. The acceleration time histories obtained on the Telescope Mount for this round are shown in Figure 4. For the Mortar Tube, Round 13, fired with an excess charge at an elevation of 1,200 mils, frequently produced maximum shock spectrum levels. The acceleration time histories for Round 13 are shown in Figure 5.

The primary shock spectra for the Telescope mount are shown in Figures 6 through 8 and a representative primary shock spectrum for the Tube is shown in Figure 9. This data shows the Mortar Tube shock levels are quite severe, being on the order of several thousand g's. Since there is a shock absorber between the Tube and the Sightunit, the shock is significantly attenuated, and the resulting instrument shock levels are on the order of several hundred g's.

An interesting feature of the field primary shock spectra, both on the Mortar Tube and on the Sightunit, is that there is generally very little difference in the primary (+) and primary (-) shock spectra. This indicates that the shock is essentially vibratory in nature, since the positive and negative responses are approximately the same, even though the initial impulse of firing the round is unidirected along the bore axis. There are also very significant responses along all three mutually prependicular axes. These characteristics of the field firing

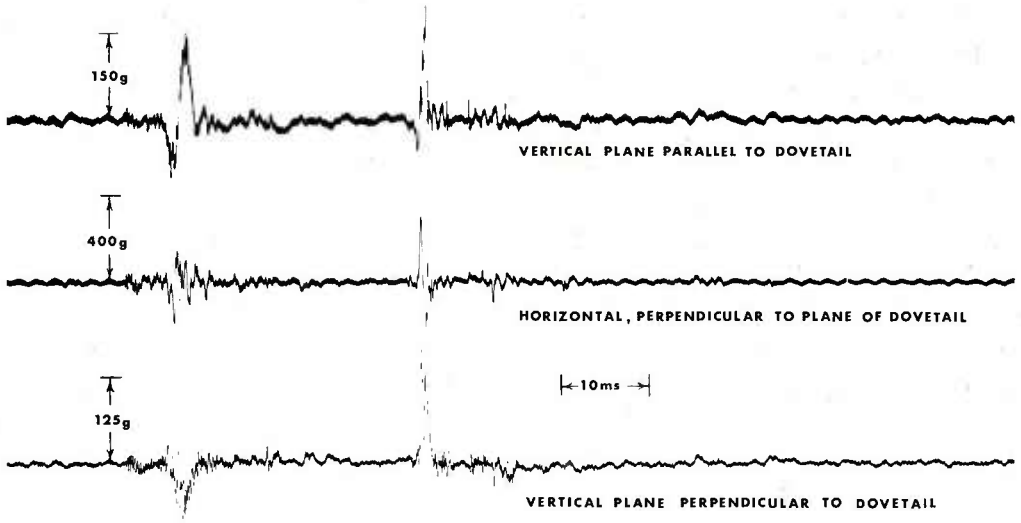


Figure 4. Acceleration Time Histories of the M29 Mortar's M53 Sightunit.

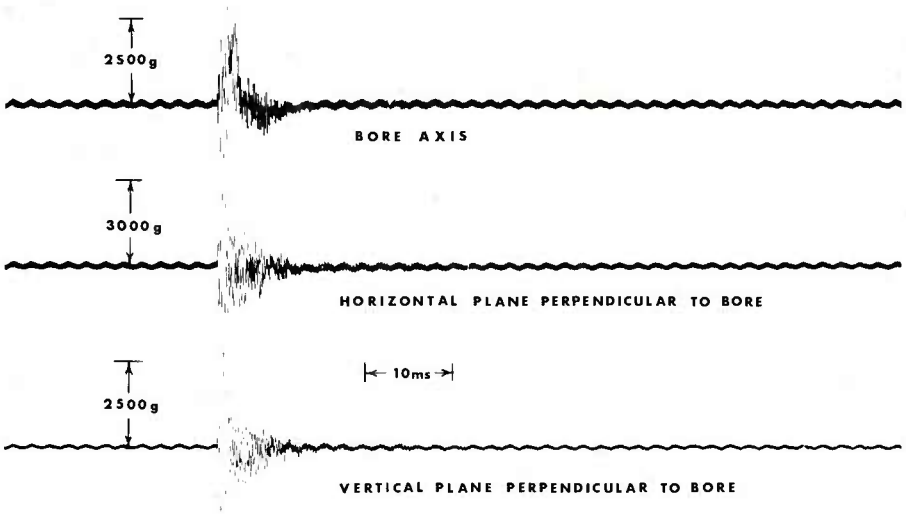


Figure 5. Acceleration Time Histories of the M29 Mortar at the Bottom of the Mortar Tube.

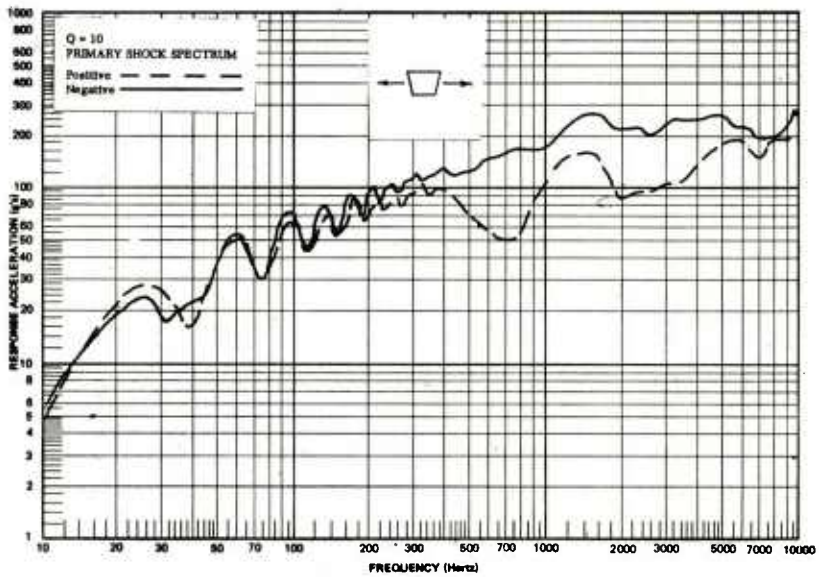


Figure 6. Primary Shock Response of the M29 Mortar's M53 Sightunit in the Vertical Direction. Firing Conditions: Standard Round at 800 mils Elevation.

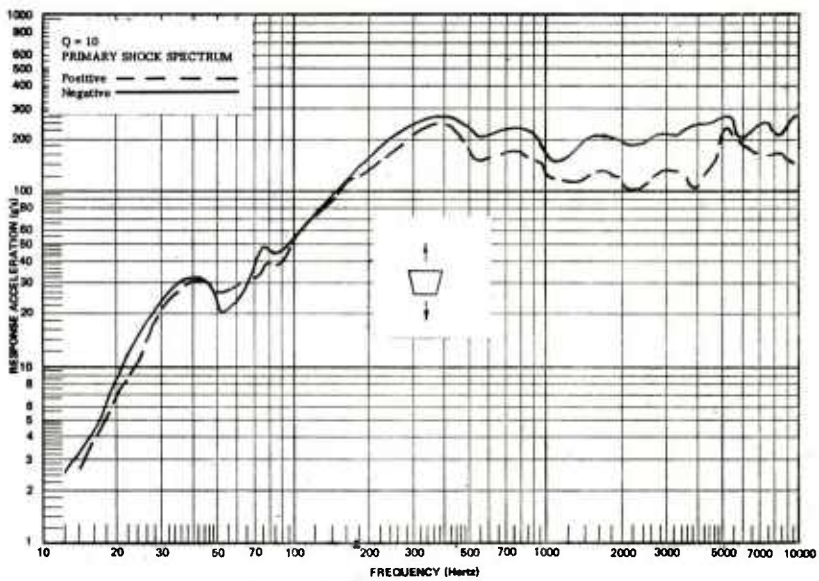


Figure 7. Primary Shock Response Spectrum of the M29 Mortar's M53 Sightunit in the longitudinal Direction. Firing Conditions: Standard Round at 800 mils Elevation.

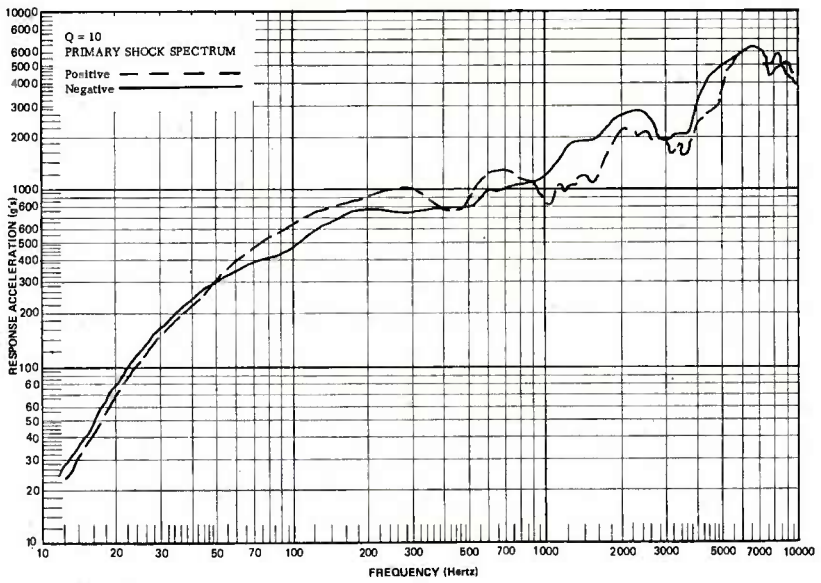


Figure 8. Primary Shock Response Spectrum of the M29 Mortar's M53 Sightunit in the Transverse Direction. Firing Conditions: Standard Round at 800 mils Elevation.

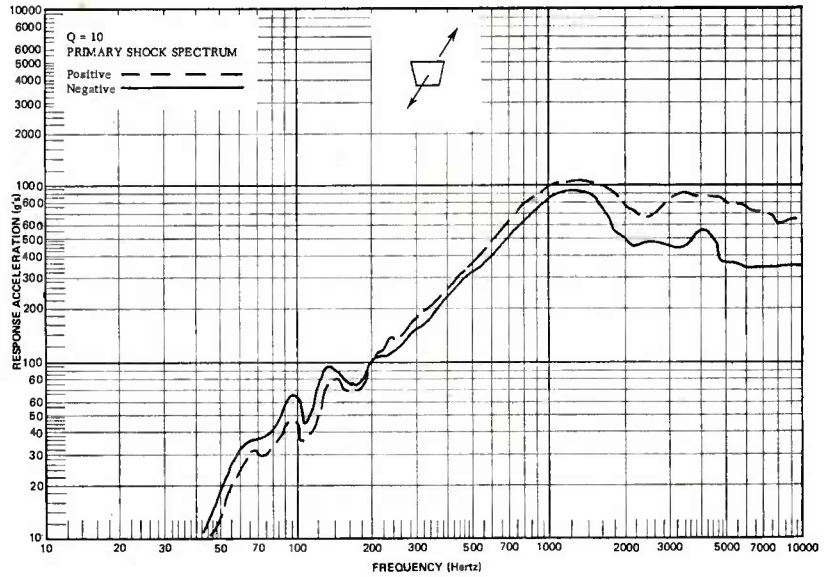


Figure 9. Primary Shock Response Spectrum of the M29 at the Bottom of the Mortar Tube in the Bore Direction. Firing Conditions: Standard Round at 1400 mils Elevation.

shock environment suggest that the laboratory shock tests may not have to be performed in both directions of a given axis, or even in all three axes. The laboratory test program outlined will determine if such test simplifications are possible. If they are, substantial cost savings can be realized during in-process testing of fire control instruments, providing the test validation procedure described in this report is performed.

Based on a study of the firing shock data, the initial laboratory shock test selected was a nominal 150 g, 1 millisecond half-sine shock pulse, to be applied in both directions of all three major axes. The intent was to conduct a test at a somewhat lower level than might actually be indicated by the data, in order to determine the general character of the Sightunit's response without causing a failure. The instrument was mounted on the shock machine, a Barry Model VP-150, and instrumented with nine accelerometers, three sets of three accelerometers, mounted on the Elbow Telescope, the Telescope Mount, and the mounting fixutre. The instrumentation consisted of Endevco Model 2224C accelerometers, Endevco Model 2760A charge amplifiers, and a Sangamo Model 3500 FM tape recorder operated at 30 inches per second. In turn, the 150 g, 1 millisecond half-sine shock was applied in each direction of the three major axes of the Sightunit, the response at all nine accelerometer locations being recorded. During the testing, there was an almost immediate indication that the test procedure was not realistic in some manner. When tested in the vertical axis with the wide part of the dovetail down, the Sightunit came out of the dovetail. This does not occur in the normal course of field firing, and is an example of the type of unrealistic effects occurring in laboratory testing that resulted in the present program. In order to keep the unit intact, the shock level had to be reduced to 100 g's in this position.

The laboratory test data from the nine accelerometer locations was analyzed in the same manner as the field data for all six positions of the Sightunit. The acceleration time histories for a positive and negative longitudinal laboratory shock are shown in Figures 10 and 11 and the corresponding primary (+) and (−) shock spectra for the Telescope Mount channels are shown in Figures 12 through 15. Figures 10 and 11 show the directionality of the laboratory shock in the fixture's longitudinal time history (top trace) and in the three mount time histories (bottom three traces). In general the time histories of the telescope show little directionality, and are more representative of a vibration than a shock. Examination of the laboratory test spectra, in Figures 12 through 15, also reveals some interesting features. As with the field spectra, the positive and negative responses for the Telescope Mount are very similar, frequently being so close that they cannot be identified separately. This suggests that in the laboratory, testing in each direction of a given axis may not be necessary. The most striking feature is that substantial responses are generated in all three axes, when applying excitation only in the longitudinal axis. Comparing the laboratory shock spectra for the Telescope Mount, with those obtained from the field firing data reveals that the laboratory

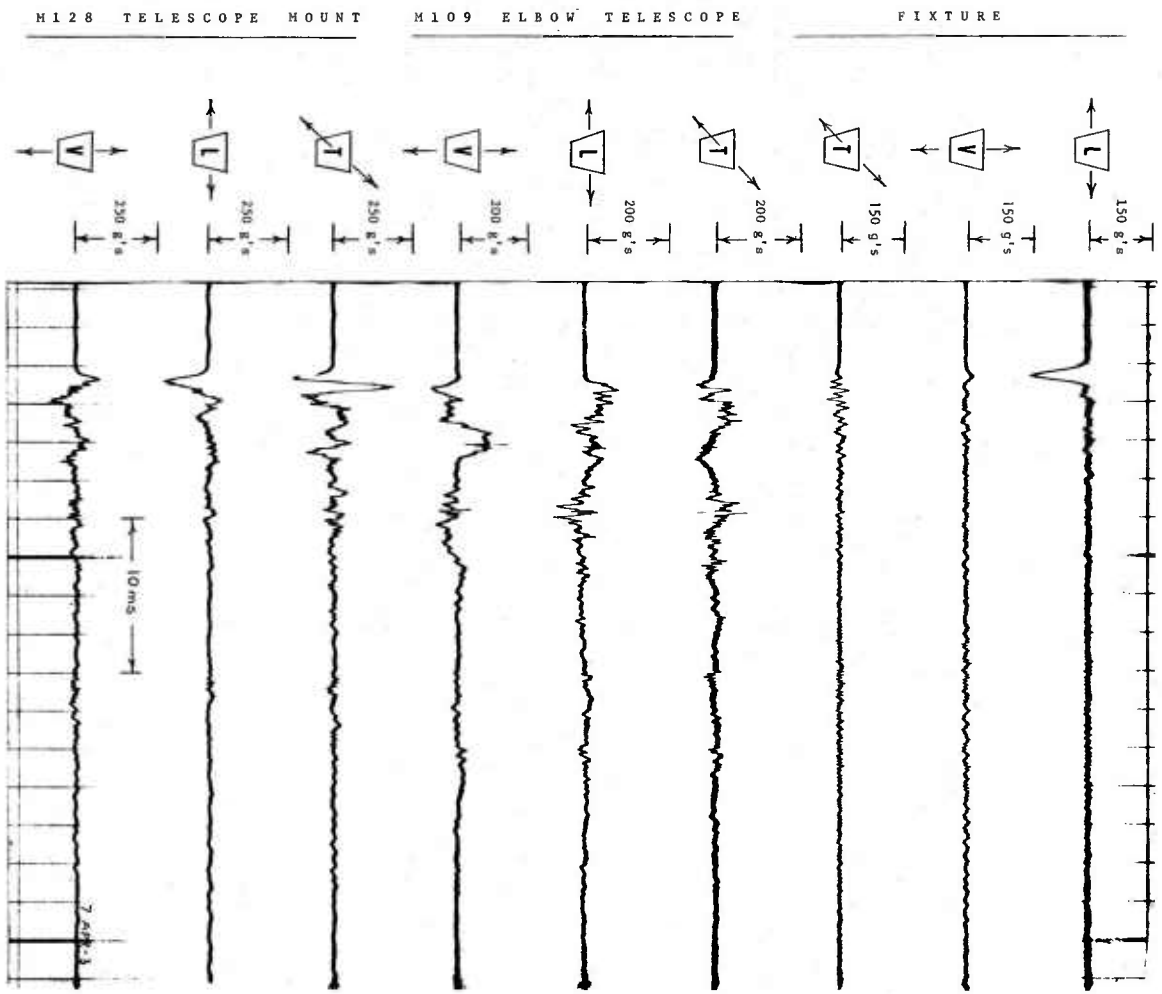


Figure 10. Acceleration Time Histories of the M29 Mortar's M53 Sightunit due to 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.

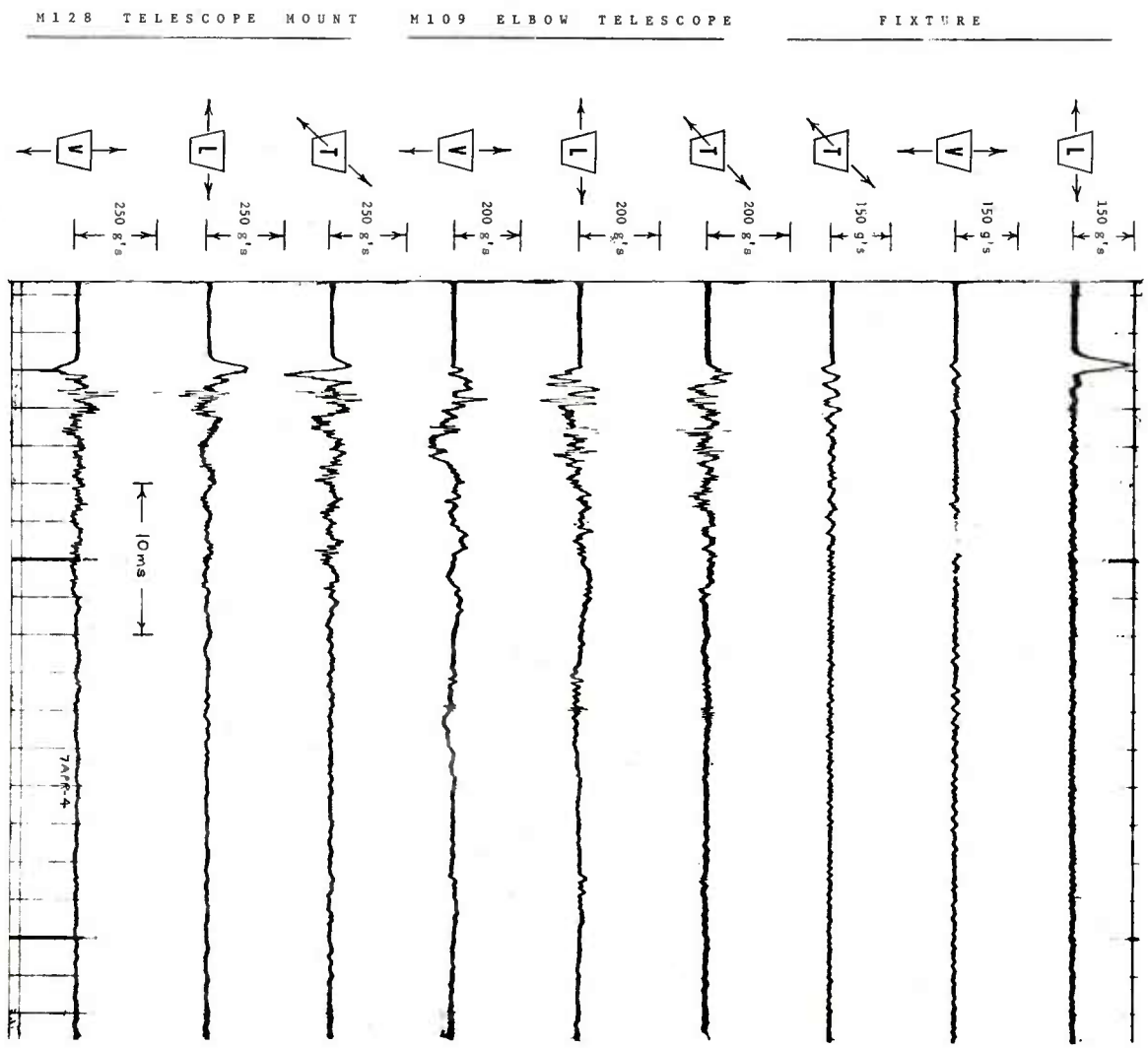


Figure 11. Acceleration Time Histories of the M29 Mortar's Sightunit due to a 150 g, 1 Millisecond Half-Sine Shoc in the Longitudinal (Aft) Direction.

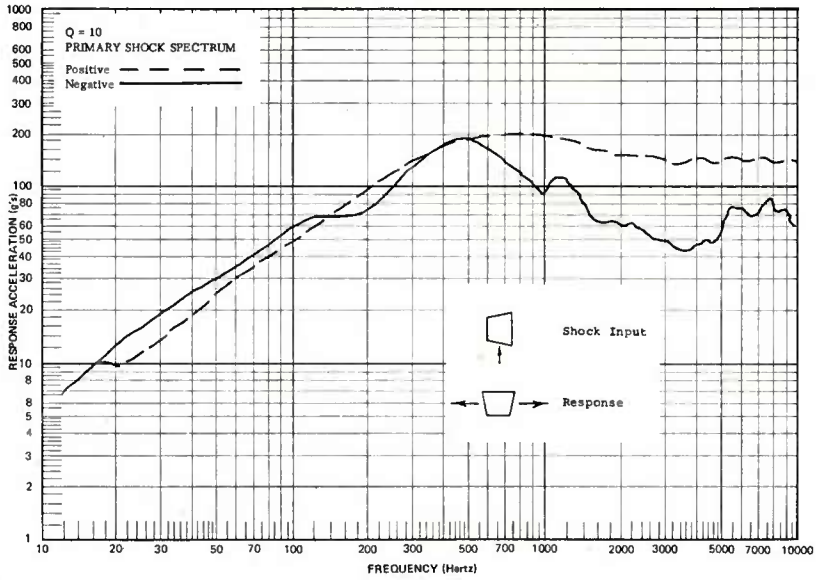


Figure 12. Primary Shock Response Spectrum of the M29 Mortar's M128 Telescope Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.

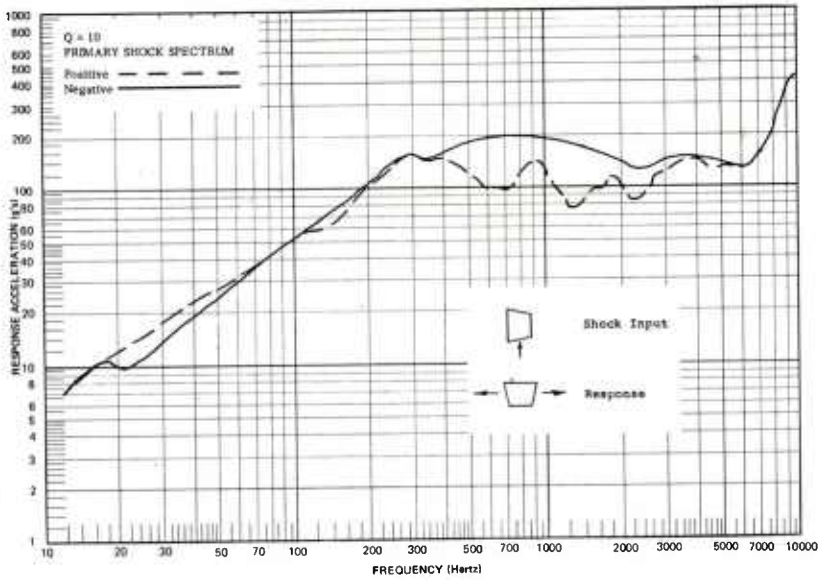


Figure 13. Primary Shock Response Spectrum of the M29 Mortar's Telescope Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Aft) Direction.

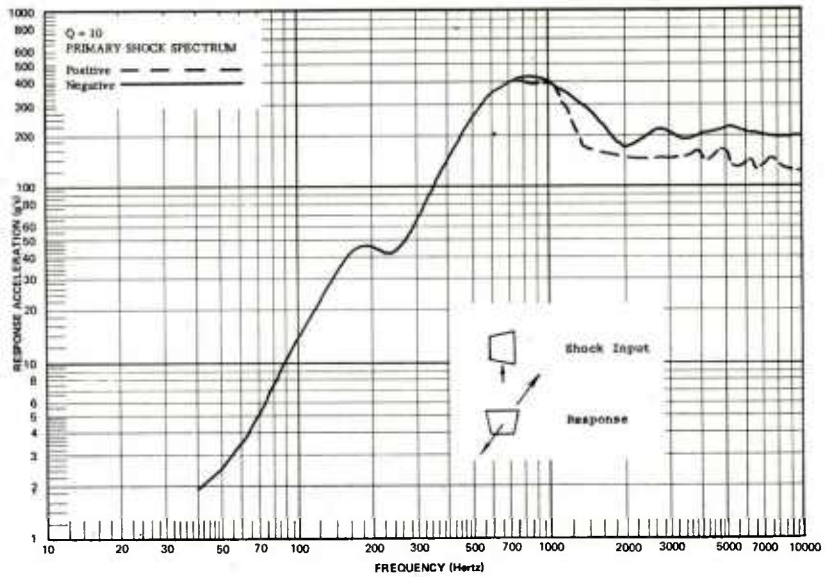


Figure 14. Primary Shock Response Spectrum of the M29 Mortar's M128 Telescope Mount in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.

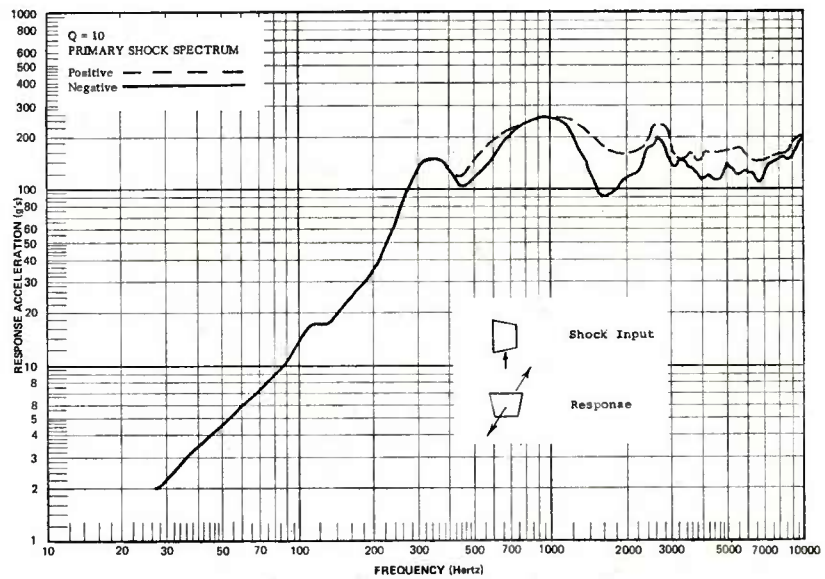
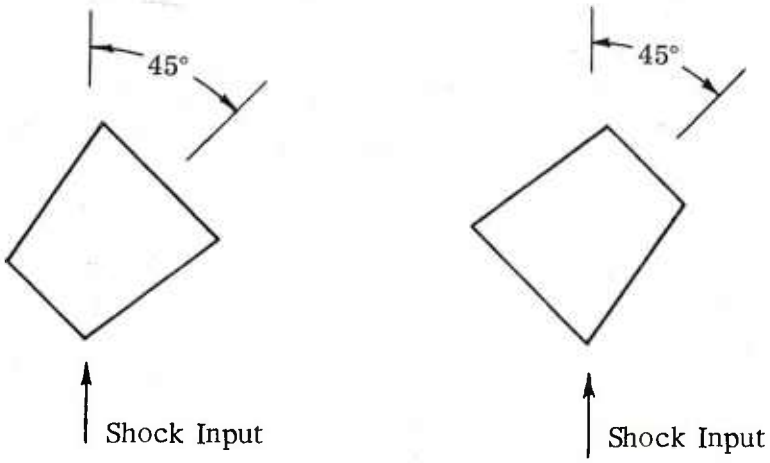


Figure 15. Primary Shock Response Spectrum of the M29Mortar's M128 Telescope Mount in the Transverse Direction due toa 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal (Forward) Direction.

test produces only a fair simulation; the best simulation being provided by testing in the longitudinal and transverse axes. The general shape of the spectra obtained in these tests at each accelerometer location is very similar to the corresponding field spectra, with those from the laboratory test being of lower magnitudes. This indicates a need for a shock test at a higher level, with approximately the same time duration.

The next laboratory test performed on the M53 Sightunit used a nominal 200 g, 1 millisecond half-sine shock pulse, with the unit being tested in only five positions. Since the test in the vertical axis with the wide part of the dovetail down had to be limited to only 100 g's, this position was eliminated. The same locations were monitored as in the first test, and the data was again analyzed in the form of primary (+) and (−) spectra for 5% damping. As could be expected, the spectra did not differ markedly from those obtained in the first test, being of the same general shape but at a higher level. To reduce the immense volume of data in this report, only the critical spectra will be shown for the remainder of this discussion. Again, shocks applied in the longitudinal axis generated significant responses in all three axes. Figures 16 and 17 show the comparison between field and laboratory spectra in the vertical and longitudinal axes due to laboratory shock applied in both directions of the longitudinal axis. Figure 18 shows the comparison of field and laboratory spectra for the transverse axis. The transverse laboratory spectra were obtained with the unit suspended from a horizontal surface and the shock applied perpendicular to the plane of the dovetail.

Comparison of the field and laboratory spectra shows that the simulation is only fair, the longitudinal axis perhaps being overtested, and the vertical and transverse axes being undertested. If the shock level is increased to achieve better simulation in the vertical and transverse axes, the longitudinal axis would probably receive a considerable overtest. The general shape of the laboratory and field spectra were similar, but the overall simulation was not considered satisfactory. Recalling that in actual field firing the Mortar Tube axis and the dovetail axis are often 45° to one another, a test was performed simulating this condition. The fixture was oriented so that the dovetail axis was at 45° from vertical and shocked in two positions at a level of 250 g's as shown below.



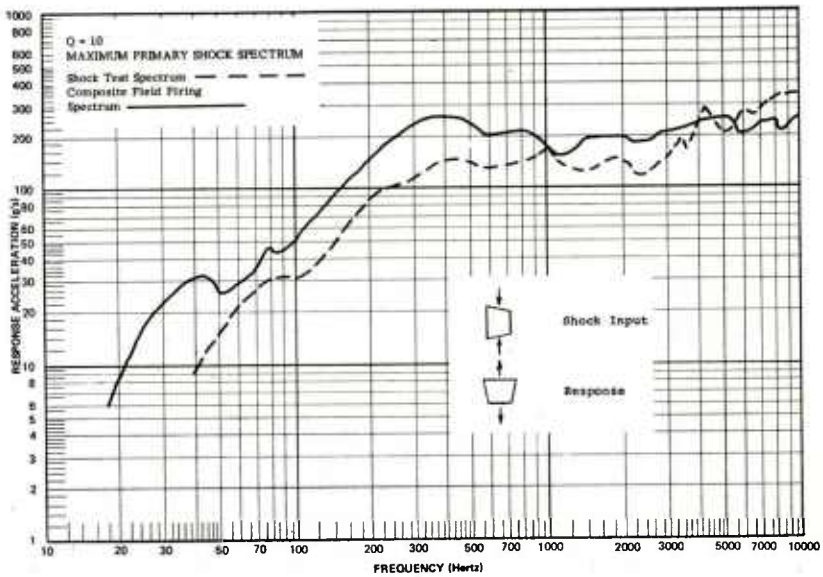


Figure 16. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope in the Vertical Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.

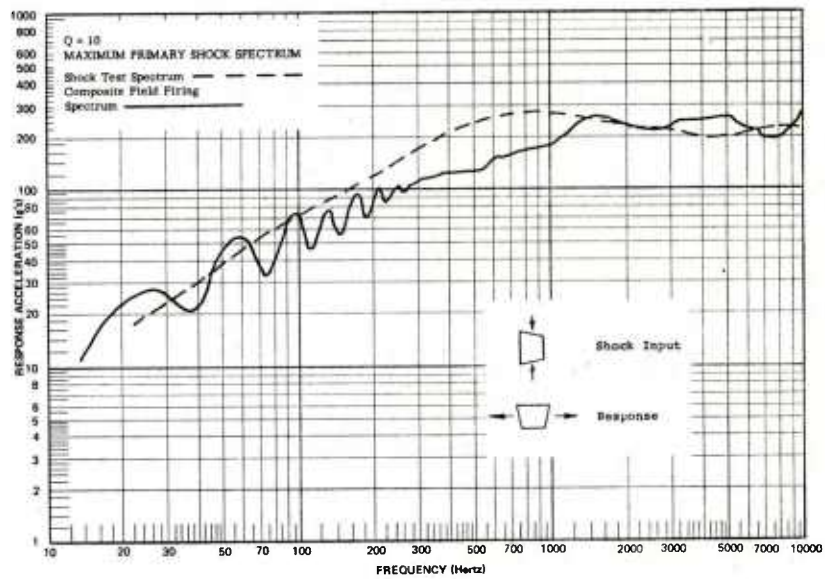


Figure 17. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope in the Longitudinal Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.

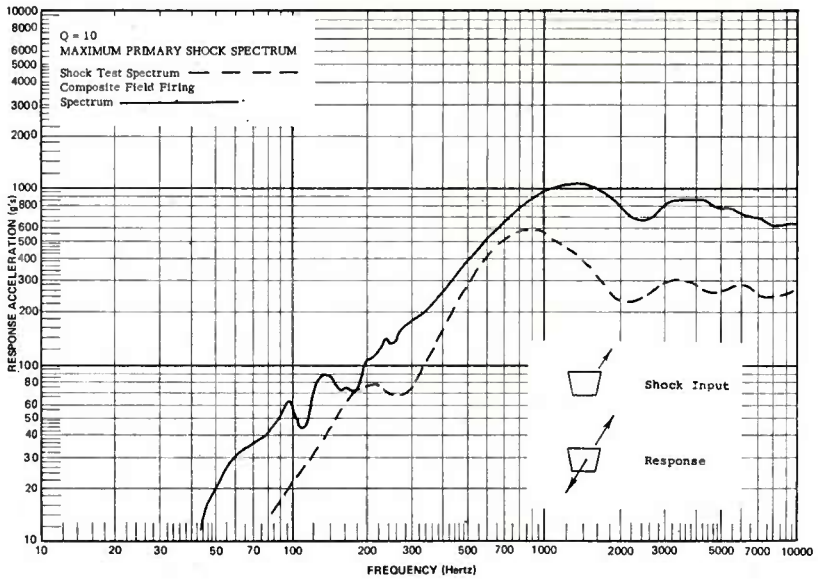


Figure 18. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's Telescope in the Transverse Direction due to a 200 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.

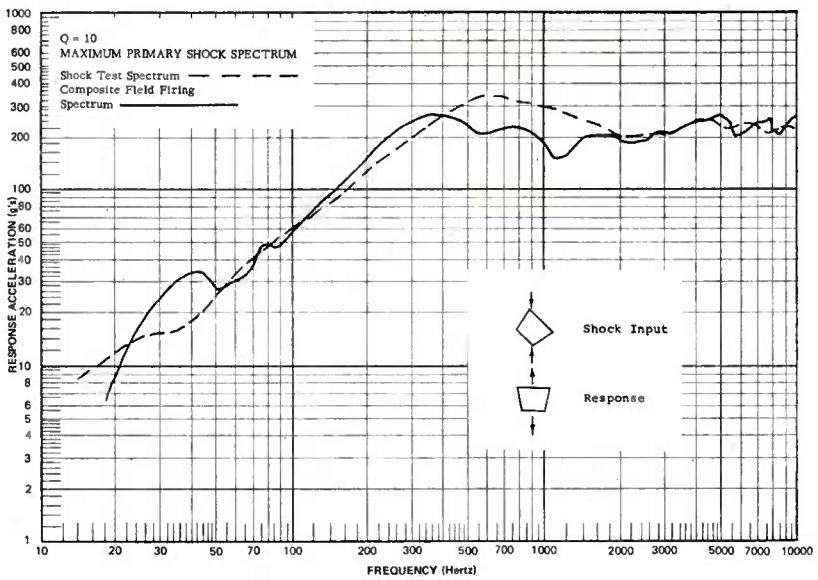


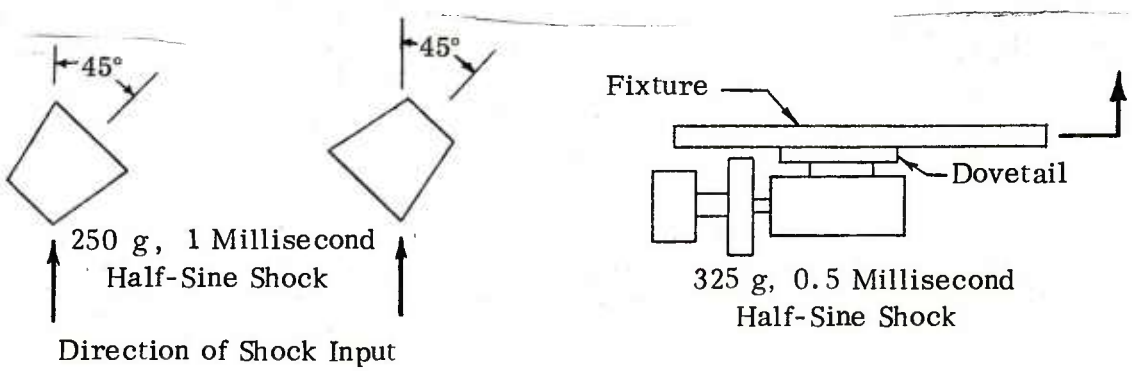
Figure 19. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Vertical Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Vertical Plain at 45° to the Longitidinal Axis.

The resulting shock spectra for the vertical and longitudinal axes of the M128 Telescope Mount are shown in Figures 19 and 20 compared with the field firing spectra. For these two axes, the correlation is considered to be quite good. The general shape of the field and laboratory spectra are very similar and the magnitude of the differences, either over or under, are acceptable. Thus, testing the M53 Sightunit in the two 45° positions results in an excellent simulation of the field firing shock environment for the vertical and longitudinal axes. The simulation in the transverse axis was not good and represented a considerable undertest. Using the shock spectrum as a guide, it was necessary to test the transverse axis at a higher level than 250 g's, and at a duration shorter than 1 millisecond. This required making a new top plate for the box fixture to stiffen it and to reduce ringing. The top plate thickness was increased to 2 inches, and the M53 Sightunit was suspended from it and shocked at a level of 325 g's using a half-sine pulse duration of approximately 0.5 millisecond. The resulting shock spectrum from the response of the M28 Telescope Mount is shown in Figure 21 along with the field firing spectrum. Again the correlation is believed to be quite satisfactory. The general shape of the curves is similar and the degree of undertest at higher frequencies is believed to be acceptable, and much better than in any of the previous tests.

The instrument supports used for these tests were straight-forward, simple, stiff fixtures. The shock spectra computed from the mounting fixture's response in the direction of the shock input, showed a clean spectra void of any high frequency ringing and looked very much like the theoretical half-sine shock spectra. The recommended test produces a very good simulation of the field firing shock based on the shock spectra, and since only three instead of the normal six positions must be tested, the test is simpler and more economical to perform than typical test procedures such as in MIL-STD-810C.

Recommended Laboratory Shock Test

The recommended laboratory shock test for the M53 Mortar Sightunit is a 250 g, 1 millisecond half-sine shock applied at 45° to the dovetail axis in both directions and a 325 g, 0.5 millisecond half-sine shock applied in the transverse axis in the direction tending to pull the dovetail away from the sightunit. Schematically, the three test orientations are shown below.



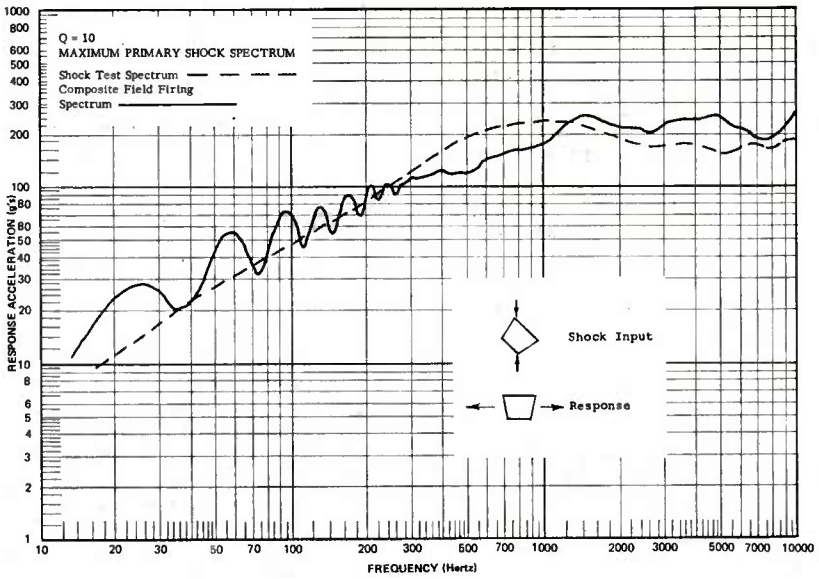


Figure 20. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Longitudinal Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Vertical Plain at 45° to the Longitudinal Axis.

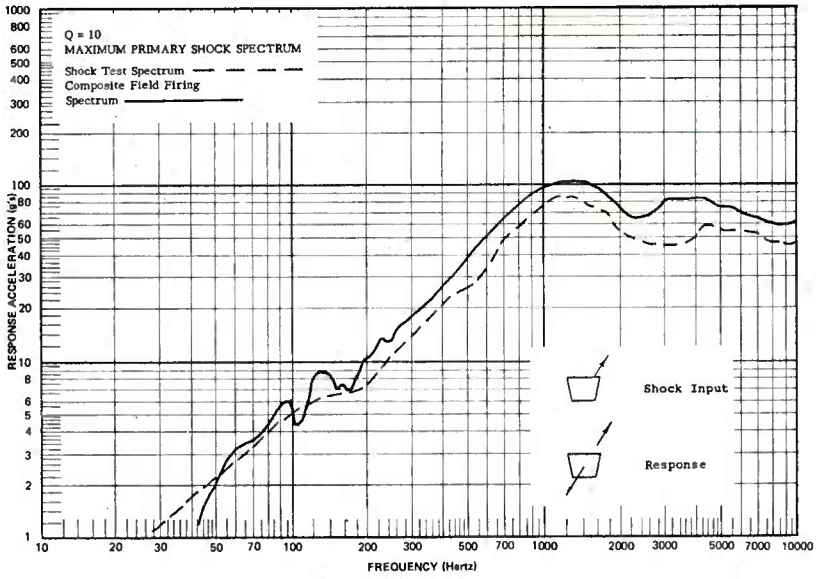


Figure 21. Comparison of Field and Laboratory Shock Response Spectra of the M29 Mortar's M128 Telescope Mount in the Transverse Direction due to a 250 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.

It is further recommended that the unit be tested for a total of eighteen shocks, six in each of the above directions. The number of shocks is the same as the present MIL-STD-810C with the exception that the eighteen shocks are for three shocks in both directions for the three axes of the unit. The recommended test eliminates testing in half of the directions.

Section 3

M102 105MM TOWED LIGHT HOWITZER

The M102 Howitzer is a direct support artillery weapon shown in Figure 22. It weighs 3,140 lbs., and it is easily transportable in aircraft or slung under a helicopter. It has a low silhouette and a rigidly constructed frame. It is designed to permit 360 degree transverse of the weapon.

The M102 Howitzer underwent test firing at Jefferson Proving Ground during a two week period in December of 1973. During this time accelerometer readings were taken at locations on the Direct and Indirect Fire Controls.[2] The Indirect Fire Control was instrumented at nine locations while the Direct Fire Control was instrumented at ten locations. Figure 22 shows the weapon with both Direct and Indirect Fire Controls Instrumented.

Laboratory Testing and Results of the Direct Fire Control

The M102 Howitzer Direct Fire Control, consisting of the M14 Quadrant and M114 Elbow Telescope, was first vibrated in the laboratory to determine its frequency response characteristics and approximate damping values. The instruments were mounted as shown in Figures 23 and 24, ten positions being monitored with accelerometers as shown in Figure 25. Using a vibration input level of ±1/2 g, the combined instruments were vibrated in each of three mutually perpendicular axes over a frequency range of 10-5,000 Hertz. The frequency response of each location was obtained in the form of transmissibility plots, and three representative curves are shown in Figures 26 through 28. Examination of Figure 26 shows a first resonance of the Elbow Telescope at about 75 Hertz, and the next highest system resonance at about 600 Hertz. Amplification of input vibration seldom exceeds a factor of 10, with this occurring at frequencies above 1,000 Hertz. This 75 Hertz resonance also appears on the Quadrant in the transverse direction but with a smaller amplitude. Figure 27 shows the isolation that the Elbow Telescope has for the longitudinal direction, and is shown in this figure as having a transmissibility less than 1.0 for frequencies above 200 Hertz. Figure 28 is a good example of a rigid system in the longitudinal direction and shows very little response in the low and mid-range frequencies. Since the highest transmissibility for the fire control is less than 10 (similar to the M53 Sightunit) a damping value of 5% was selected to be a conservative choice, to be used in the subsequent data analysis.

Field firing shock data was available on the M14 Quadrant and M114 Elbow Telescope, the measurements being obtained at the same ten positions as used in

[2]Holland, R.S. and Marcus, D., "Laboratory Shock Specifications for the Fire Control of the M110, M102 Howitzers and the M29 Mortar, Derived from Field Firing Tests," Frankford Arsenal Report R-3014, June 1974.

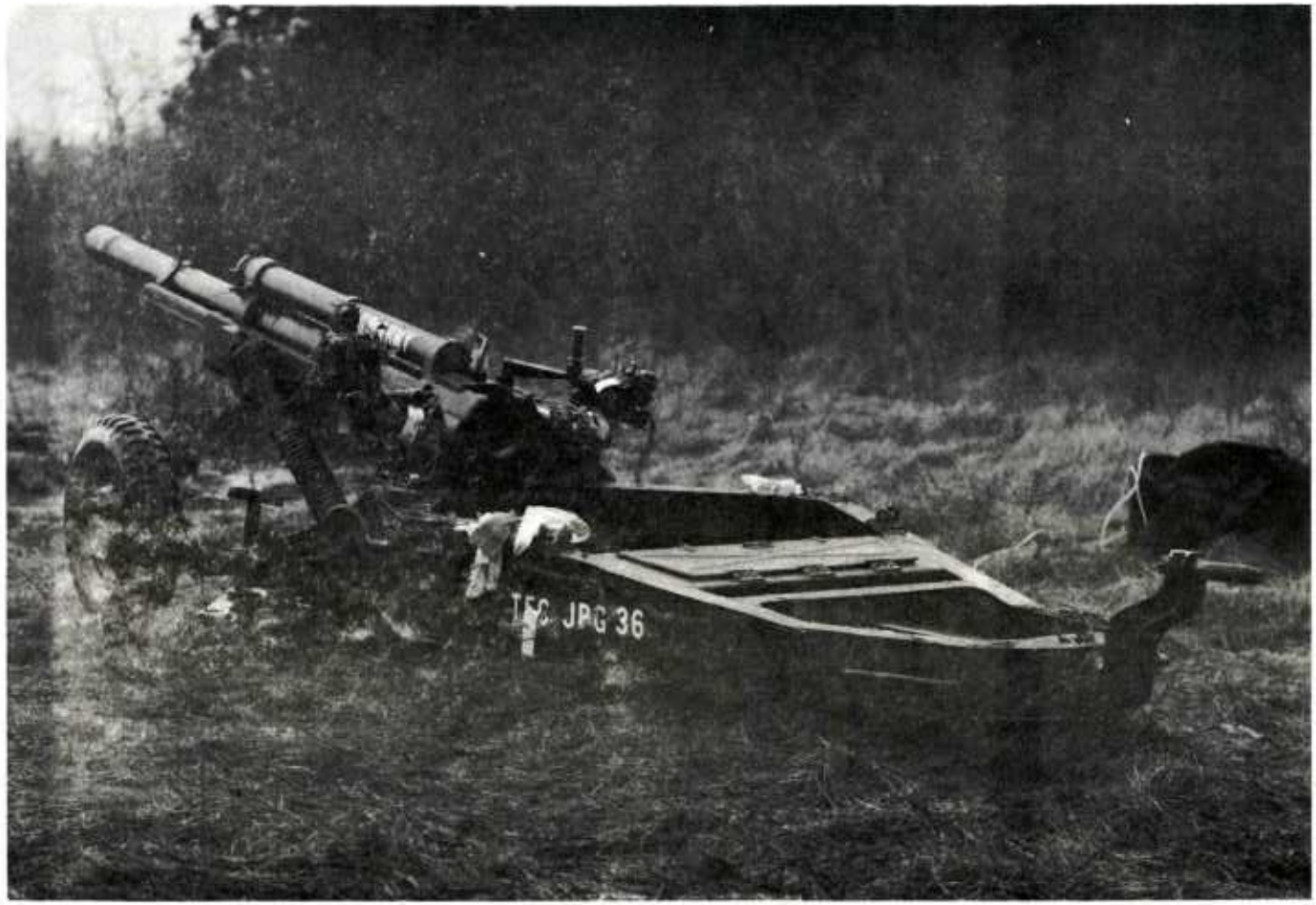


Figure 22. M102, 105MM Towed Light Howitzer.

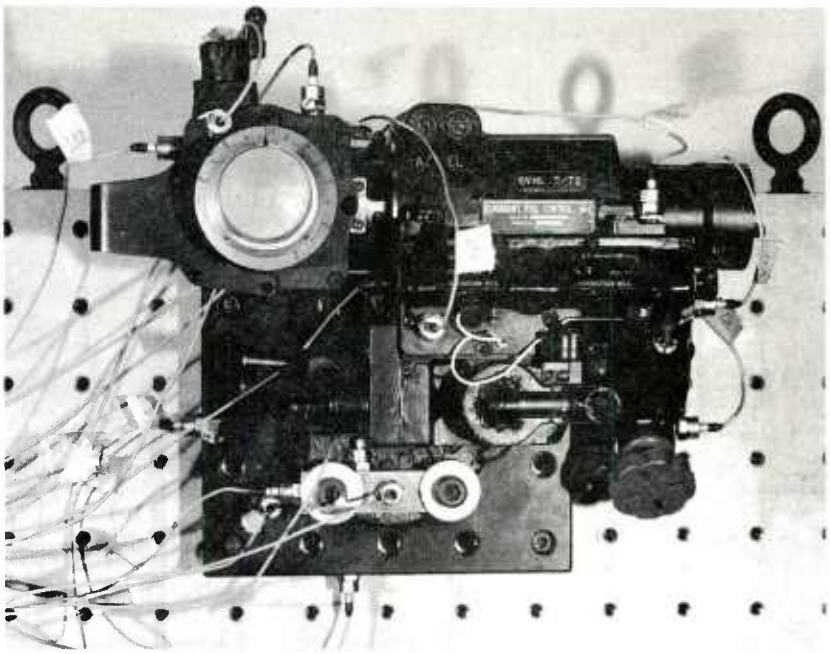


Figure 23. Front View of the M102 Howitzer's M114 Quadrant and M114 Elbow Telescope Mounted for a Positive Verticle Shock.

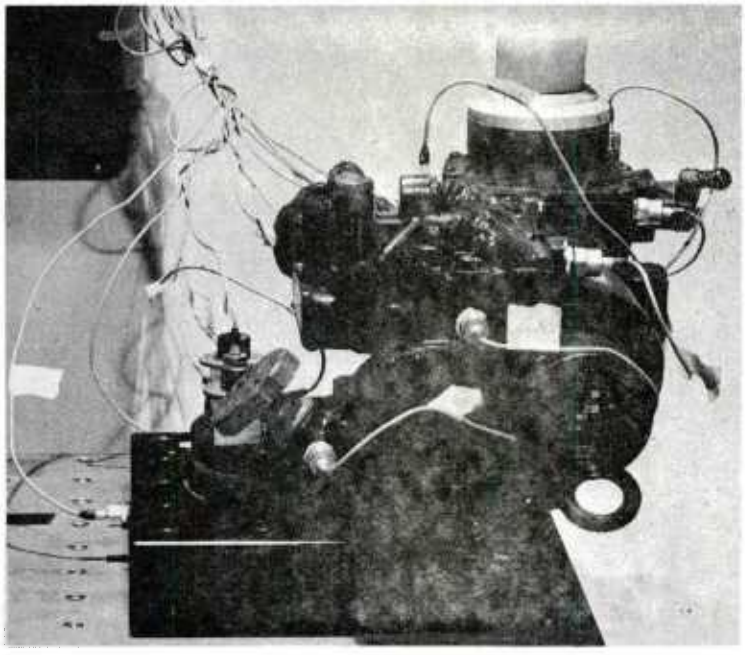
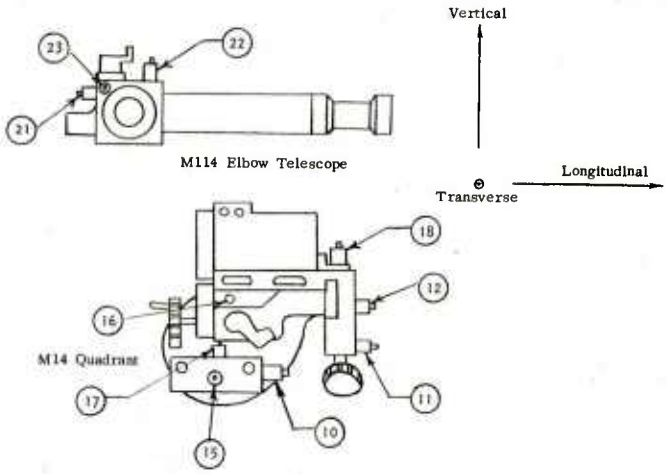


Figure 24. Side View of the M102 Howitzer's M14 Quadrant and M114 Elbow Telescope Mounted for a Positive Vertical Shock.



Position Number	Direction
10	Longitudinal
15	Transverse
17	Vertical
11	Longitudinal
12	Longitudinal
16	Transverse
18	Vertical
21	Longitudinal
22	Vertical
23	Transverse

Figure 25. Sketch of the Accelerometer Locations on the M102 Howitzer's M14 Quadrant and M114 Elbow Telescope.

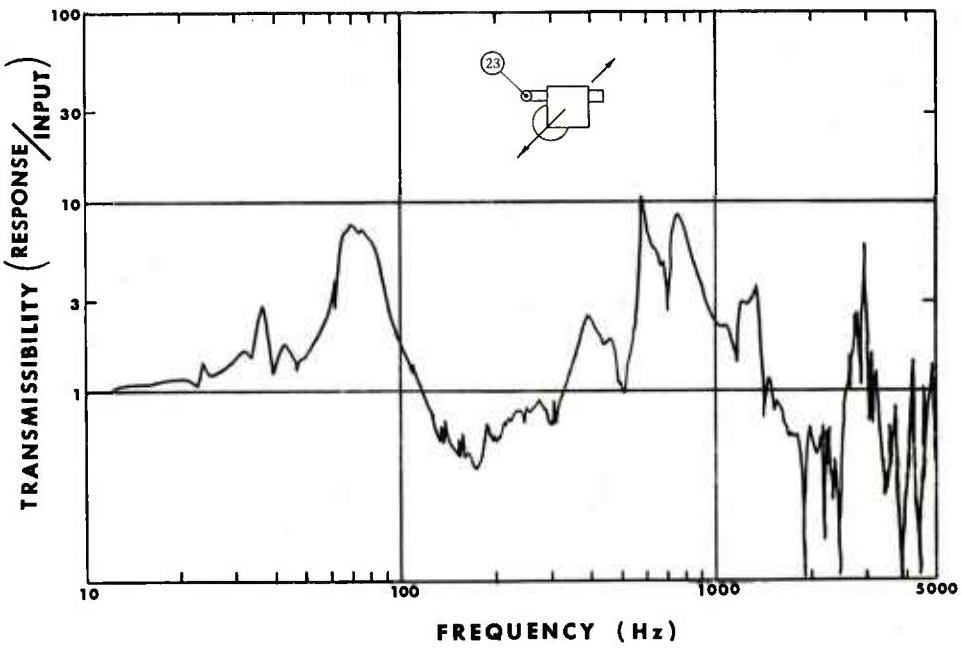


Figure 26. Vibration Response of the M102 Howitzer's M114 Telescope in the Transverse Direction, (Position 23).

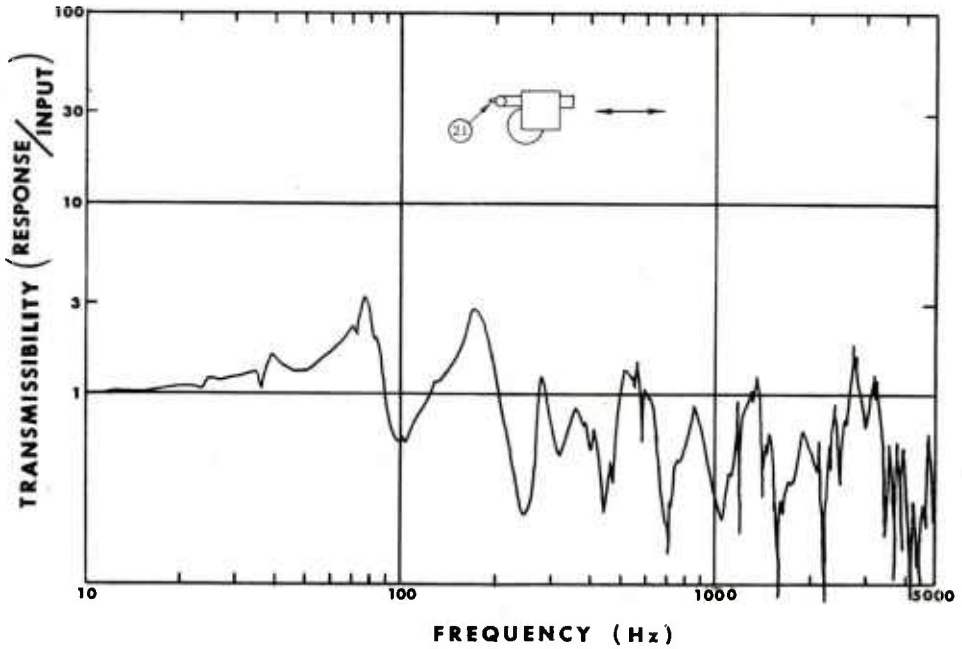


Figure 27. Vibration Response of the M102 Howitzer's M114 Elbow Telescope in the Longitudinal Direction, (Position 21).

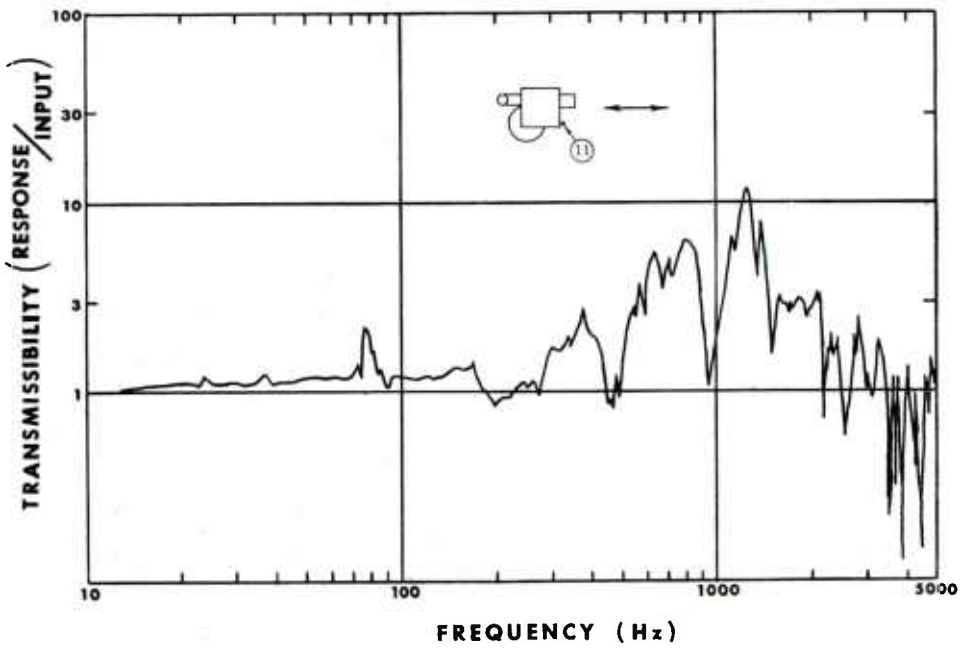


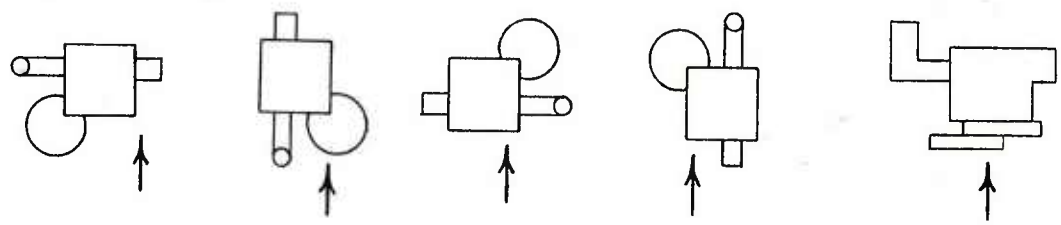
Figure 28. Vibration Response of the M102 Howitzer's M114 Quadrant in the Longitudinal Direction, (Position 11).

the transmissibility tests. The data was analyzed in terms of primary shock spectra for a 1 second period and 5% damping. The analyzer used was a Spectral Dynamics Model SD 320 Shock Spectrum Analyzer, which provided an analysis over the range from 10-10,000 Hertz. The acceleration time histories for Round 18, using an excess charge and a gun elevation of 400 mils, is shown in Figures 29 and 30. This firing condition produced maximum shock spectrum levels over much of the analysis frequency range. The composite primary shock spectra for all rounds and all ten locations monitored were used as a goal in the selection of a suitable shock test. The shock spectra for the field firings are virtually indistinguishable from one another. This indicates that the shock is essentially vibratory in nature, positive and negative responses being the same, as could be expected from the time histories.

The laboratory shock test program for the M14 Quadrant and M110 Elbow Telescope consisted of about fifty different tests at various shock test levels and time durations. A total of thirteen positions were monitored, ten on the instruments and three on the mounting fixture. The shock spectra derived from this data thus came to more than five hundred spectra, a huge volume of data. In order to keep this report to a reasonable size, only the results of the most significant tests are shown.

Examination of the field spectra for the Quadrant mounting surface shows that the input to the instruments consists predominantly of high frequency vibration, and would thus require short duration pulses for the laboratory tests. LAB Model SPA-24-400 Shock Machine was used primarily in this program because it could accommodate moderate sized instruments and could produce shock pulses with durations of one to two milliseconds. This is about the practical lower limit on pulse duration for commercially available shock test machines with the capability of testing equipment where the test item plus the fixture weigh several hundred pounds.

The first test performed on the instruments used a nominal 50 g, 1 millisecond half-sine shock pulse with the shock being applied in five different instrument positions as shown below.



This first test was performed at a deliberately low level in order to determine the general character of the instrument's response. Accelerometer data was obtained at all thirteen positions and analyzed in the form of primary (+) and (−) shock spectra. The resulting shock spectra show that the test level was too low for good simulation of the field environment, but that the pulse duration and shape would be suitable. As was noticed in the tests of the M53 Mortar Sightunit, significant

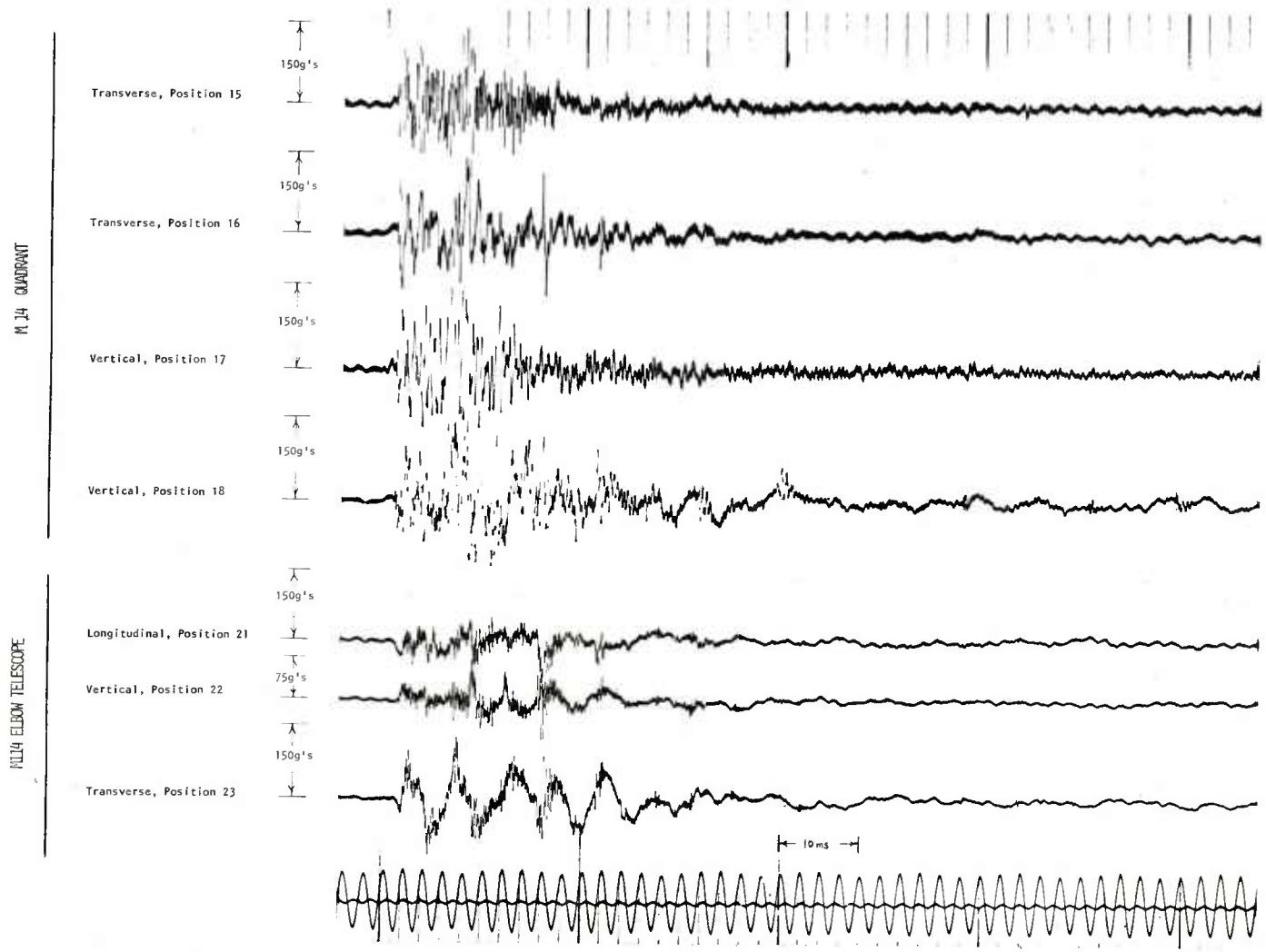


Figure 29. Acceleration Time Histories of the M102 Howitzer, at the M14 Quadrant and M114 Elbow Telescope. Firing Conditions: Excess Charge and 400 mils Elevation.

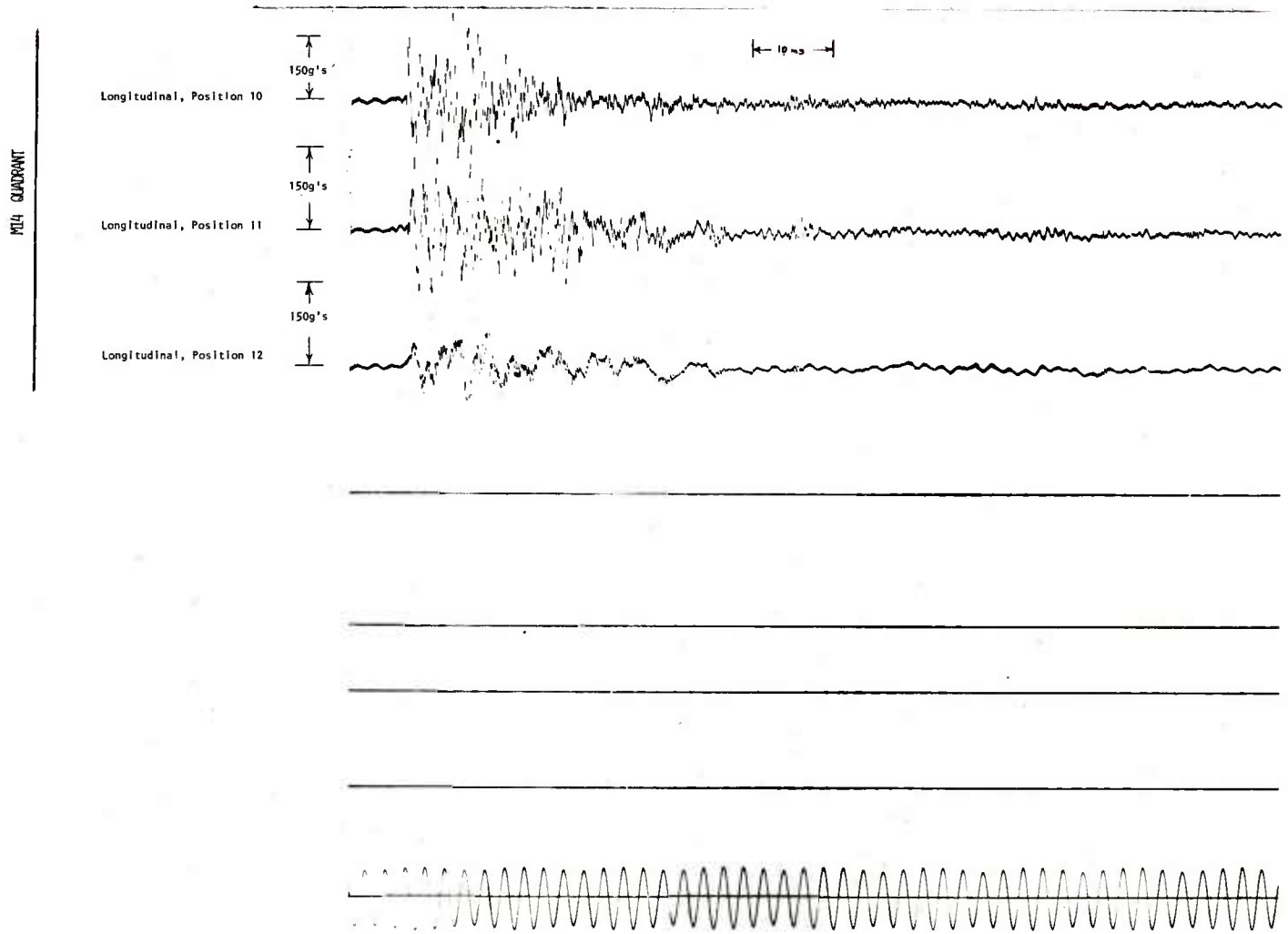


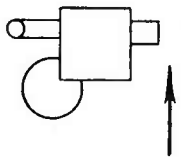
Figure 30. Acceleration Time Histories of the M102 Howitzers, at the M14 Quadrant. Firing Conditions: Excess Charge and 400 mils Elevation.

responses were generated on the Quadrant and Telescope in directions perpendicular to the directions of shock. Again this would indicate that perhaps not all item orientations would be necessary in order to achieve satisfactory simulation of the field environment.

In the next series of tests, the shock level was increased to about 100 g's, using a half-sine shock pulse of 2 millisecond duration. Again, the item was shocked in five orientations, and the data from the thirteen positions was analyzed in the form of shock spectra.

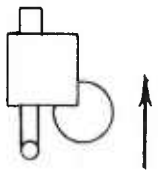
Examination of the spectra shows that on the Quadrant, the laboratory simulation is fair up to about 500 Hertz, but is a considerable undertest at higher frequencies. The simulation is better at positions farther away from the mounting area; all three telescope positions have a fairly good simulation. In general, the laboratory test should be a little more severe. At this time in the program, it was realized that the telescope had been inadvertently oriented near its highest position in the field test, rather than in the horizontal position as had been assumed. It was thus necessary to orient the telescope the same way for the laboratory tests in order to make a valid comparison of response data. For subsequent tests, the telescope was positioned near its maximum cant angle of about 40°.

Many laboratory tests were subsequently performed at higher levels and with different shock pulse durations. The best simulation achieved included tests in three positions, the shock being applied in only one direction in the vertical, longitudinal, and transverse axes. These tests used a 2 millisecond half-sine shock pulse of 175 g's for both the vertical and the longitudinal axes and 75 g's for the transverse axis. The results are shown, Figures 31 to 40, as recommended laboratory shock spectra compared to their respective compsite field spectra. The composite field spectrum comprises the maximum primary response at each frequency for a given accelerometer location from the field tests using various propellant charges and gun elevations. Thus a field composite may be composed of many gun positions fired with various propellant (generally "excess") charges. Diagrammed below are the three recommended test positions.

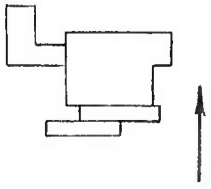


Vertical Axis

175 g, 2 Millisecond
Half-Sine Shock



Longitudinal Axis



Transverse Axis

75 g, 2 Millisecond
Half-Sine Shock

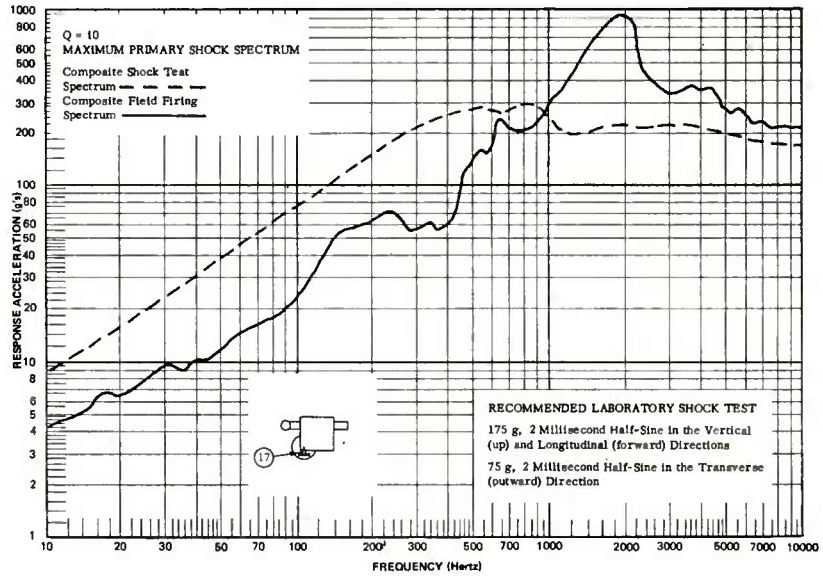


Figure 31. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Vertical Direction, (Position 17).

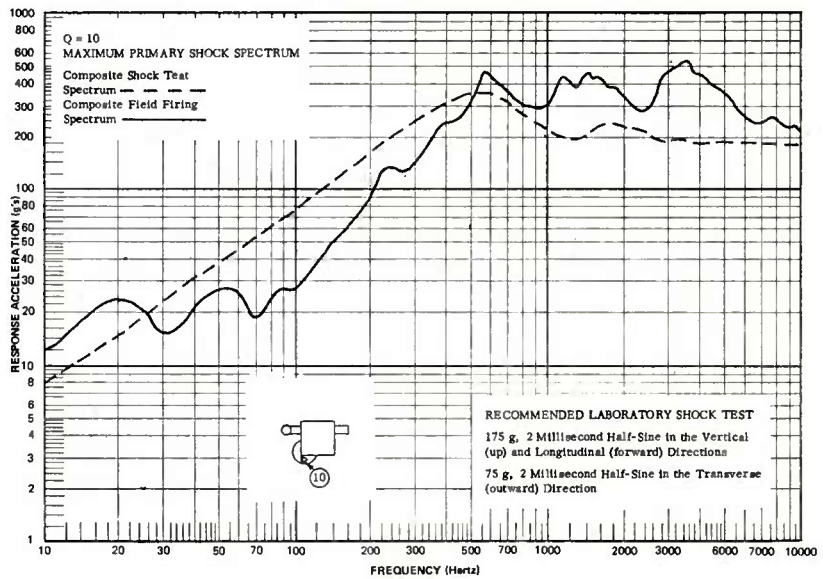


Figure 32. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 10).

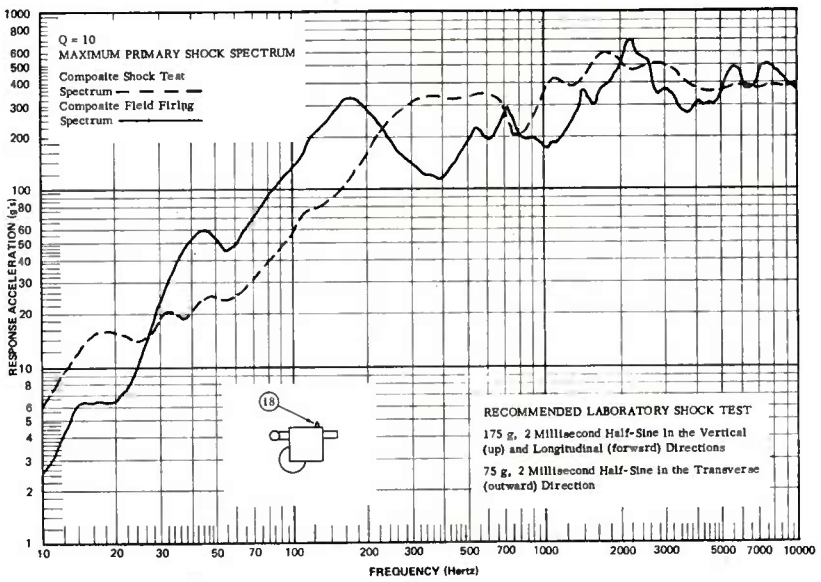


Figure 33. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Transverse Direction, (Position 15).

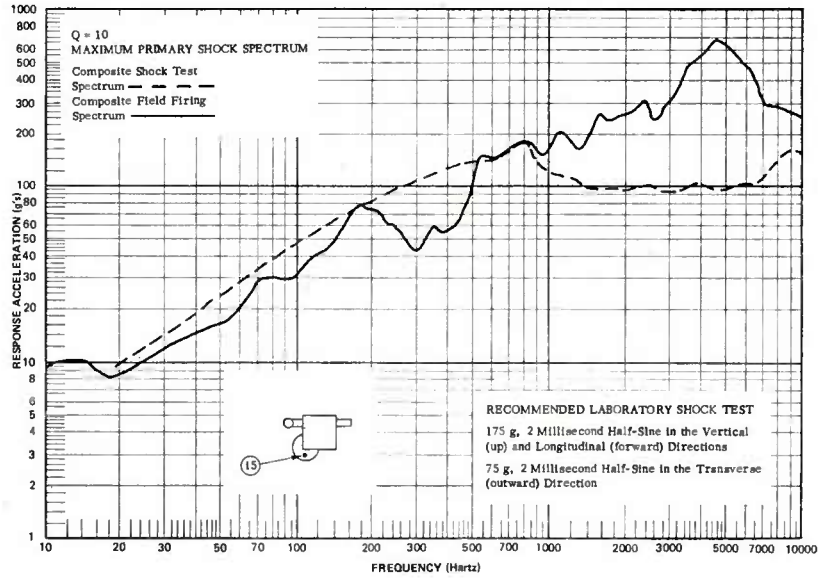


Figure 34. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M14 Quadrant in the Vertical Direction (Position 18).

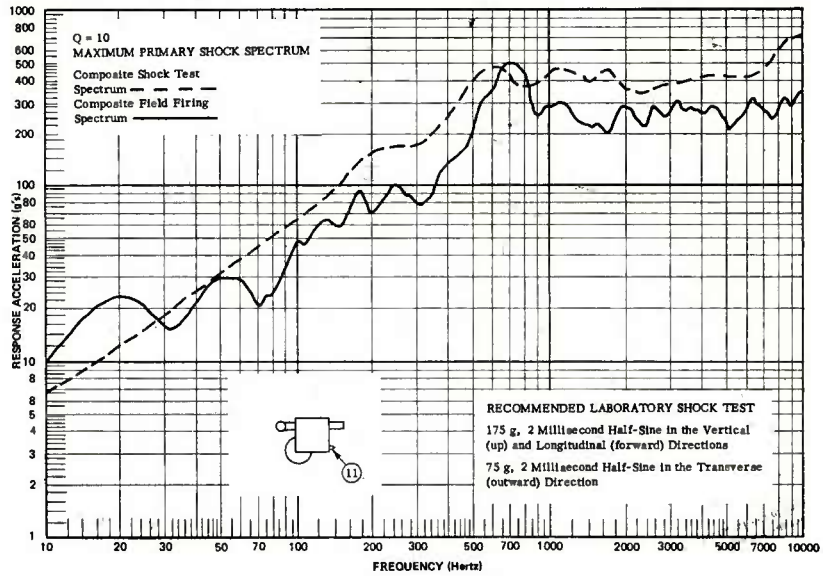


Figure 35. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 11).

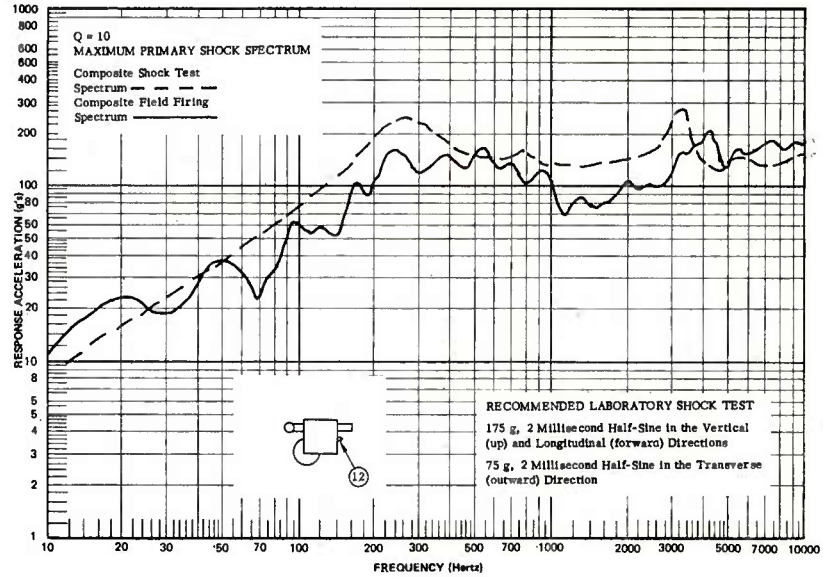


Figure 36. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Longitudinal Direction, (Position 12).

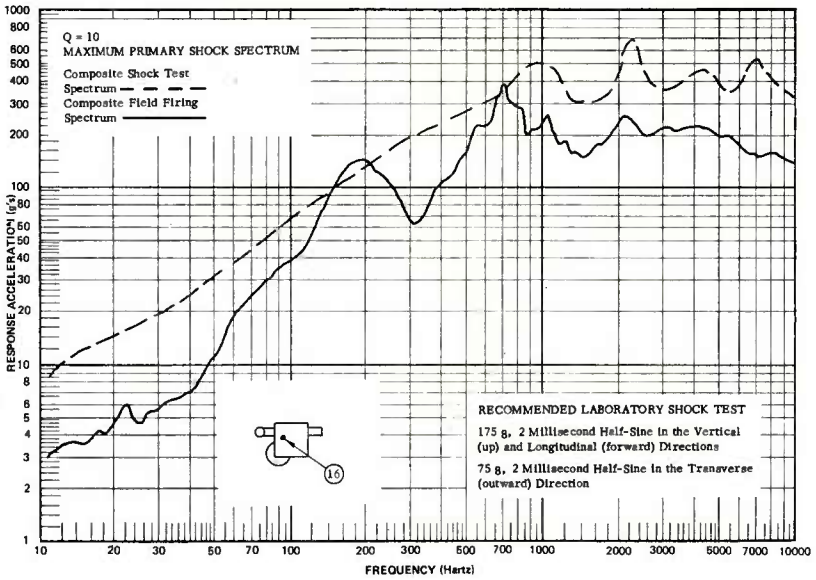


Figure 37. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M14 Quadrant in the Transverse Direction, (Position 16).

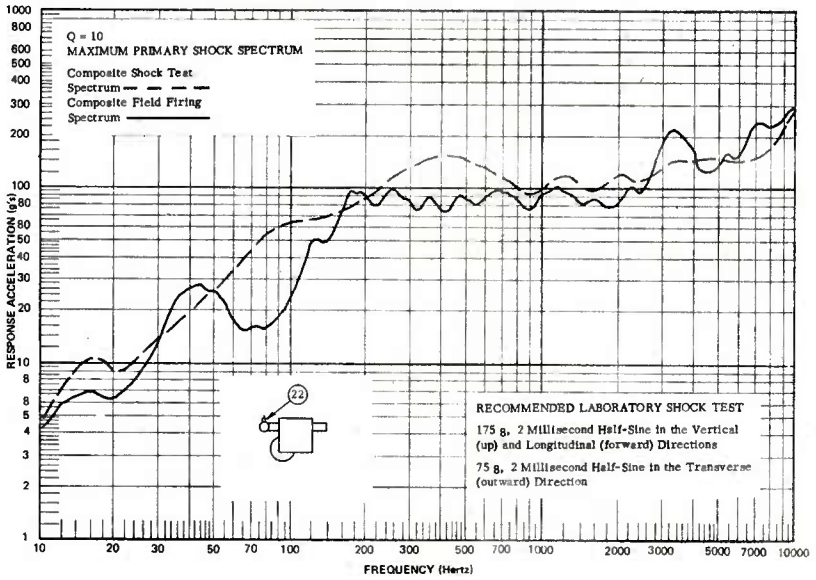


Figure 38. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Vertical Direction, (Position 22).

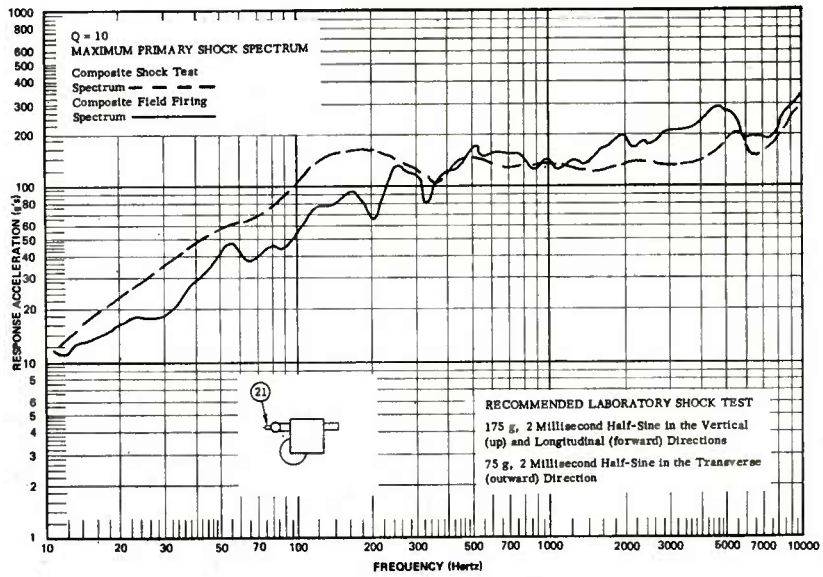


Figure 39. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Longitudinal Direction, (Position 21).

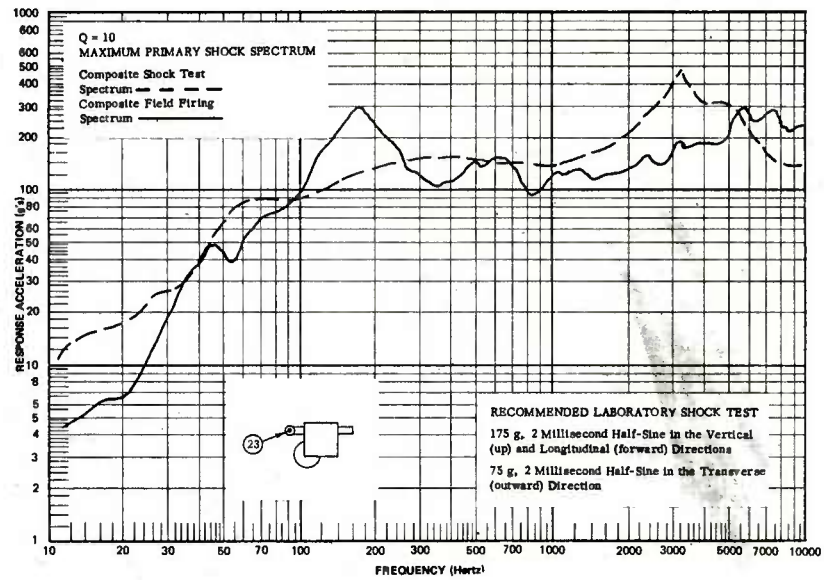


Figure 40. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M114 Elbow Telescope in the Transverse Direction, (Position 23).

Figures 31 through 33 show the comparisons for positions 10, 15 and 17, which represent the input to the Quadrant in the three orthogonal directions. These figures show the laboratory shock spectra as being greater than the field firing spectra for the low and mid-range frequencies. The response acceleration for these levels is so low, that this slight overtest was acceptable. Figures 34 through 37 represent the response of the Quadrant and also the input to the telescope. Figure 37 shows a laboratory overtest, but necessary to match the extremes of the spectrum. Most of the concern and emphasis of the program was on fitting the spectra of the telescope, and Figure 38 through 40 show this. The 180 Hertz undertest shown in Figure 40 was a result of a torsional response of the M102 Trunnion, and this response could not be duplicated in the laboratory without going to complex fixturing, which this program did not want to use.

Recommended Laboratory Shock Test

The recommended laboratory shock test for the M102 Direct Fire Control is to shock the unit six times along each of the three axes of vertical, longitudinal, and transverse for a total of eighteen shocks. A test of 2 millisecond half-sine pulses of 175 g's for both the vertical (up) and longitudinal (forward), and 75 g's for the transverse (outward) is recommended. No testing is required for the reverse of these three directions.

Laboratory Testing and Results of the Indirect Fire Control

Figure 41 is a close-up of the Indirect Fire Control mounted on the weapon. Figure 42 shows the fire control mounted on the LAB Shock Machine ready for a positive vertical shock. The nine accelerometer locations shown in Figure 42 are the same as those used for the field firing tests. The data from the field firing tests were reduced using the shock spectrum method. To compute and plot these spectra, the Ling Electronics Automatic Response Analyzer Model ASRA-40/60/80 was used. The data reduction of this test firing was performed for Frankford Arsenal by Holland and Marcus[2]. The field test data was initially analyzed using a critical damping factor of .01 (Q = 50).

In order to establish damping values for the fire control, laboratory sine sweep vibration tests were conducted. The Indirect Fire Control was vibrated in the three orthogonal directions which are parallel to the trunnion axis, vertical and horizontal. The sine vibrations were run from 10 to 5,000 Hertz for a constant acceleration input of 1/2 g. This low level acceleration is considered to be conservative insofar as yielding higher transmissibilities for the system. The higher the input acceleration

[2]Holland, R.S. and Marcus, D., "Laboratory Shock Specifications for the Fire Control of the M110, M109 and M102 Howitzers and the M29 Mortar, Derived From Field Firing Tests," Frankford Arsenal Report R-3014, June 1976.

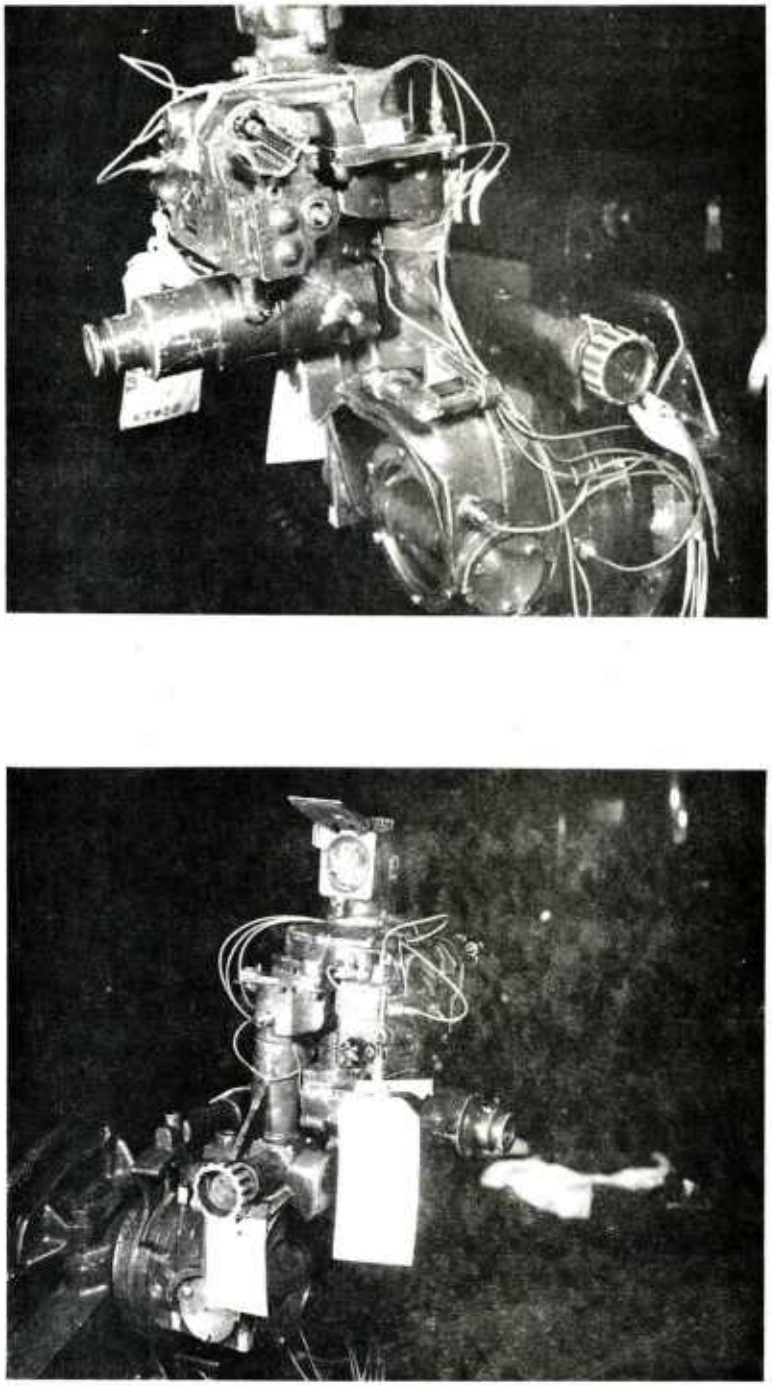
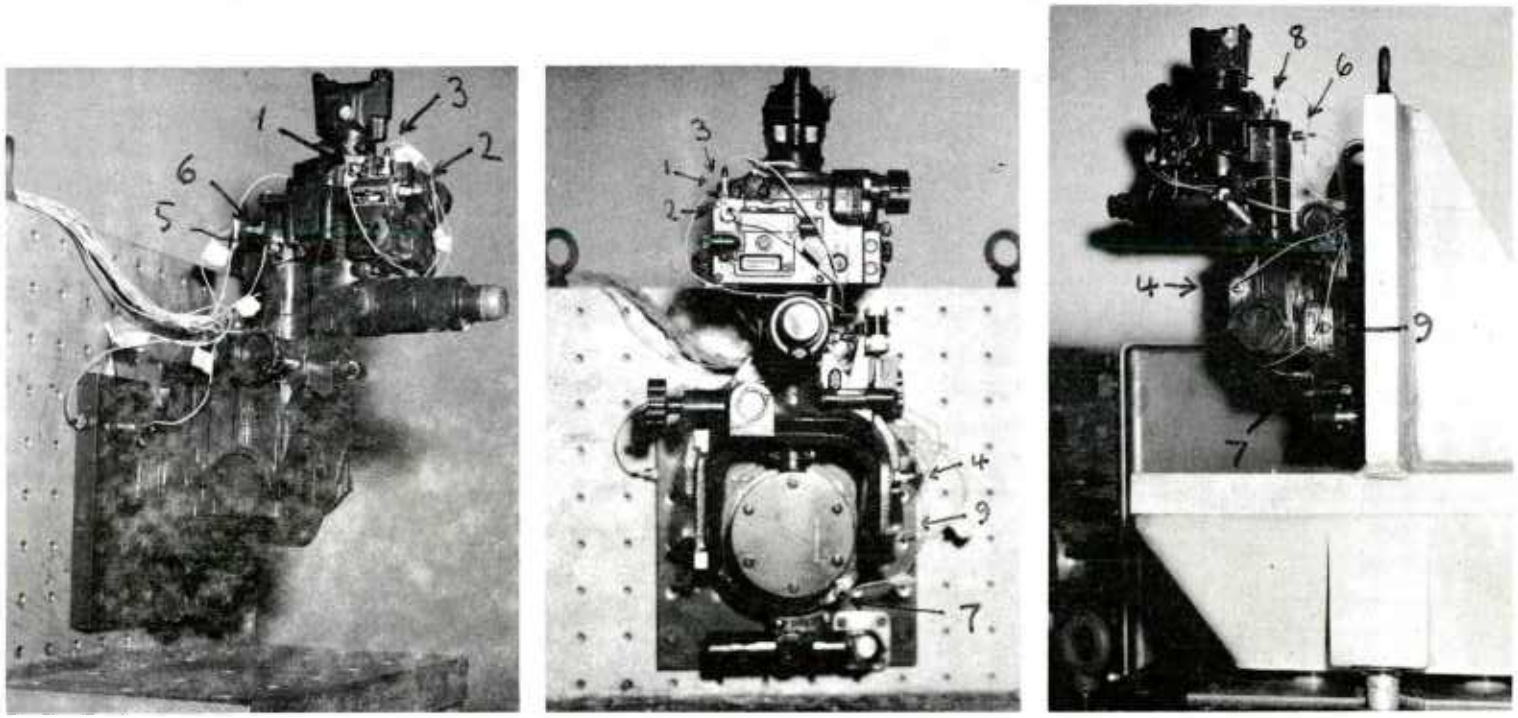


Figure 41. Indirect Fire Control System of the M102 Howitzer, Comprised of the Telescope Mount M134 and the Panoramic Telescope M113.



Left View Front View Right View

Figure 42. Indirect Fire Control Mounted for a Positive Vertical Shock on the LAB Shock Machine, Showing the Accelerometer Locations.

level, the more structural components can break free from any friction and introduce damping. Also the higher the structural stress which is proportional to the material damping present in the structural system. The response accelerations were plotted as a function of frequency. Table I shows the peak of these transmissibility curves in decibels and Q with its associated frequency. The highest Q for the system was obtained at the base of the mount in the trunnion direction for a trunnion input, and this is shown as accelerometer location 7 which is a Q of 9 at 800 Hertz. Figure 43 shows this particular plot, which has 10 db per major division for the ordinate and frequency as the abscissa. From the damping information shown in Table I, a Q of 10 was selected as being conservative for use in the computation of the shock spectra. As mentioned previously the shock spectra for the field firing data had already been computed using a Q of 50, this computation was performed again using a Q of 10.

Shock spectra were computed for eight of the nine accelerometer locations from the field firing data, since one location (input to the sight in the vertical direction) was not available due to instrumentation problems. For these eight locations, spectra were computed for all firing conditions and then combined to envelope the spectra forming eight composite spectra of all firing conditions. These composite spectra are shown in Figures 44 through 51 as the solid line. There were many firing conditions that contributed to the worst case shock spectra, but by and large all were for a zone 7 charge, some having 8 oz. of excess propellant. The majority of the spectra were for an elevation of 850 mils, with 200 and 600 mils also contributing. Figure 52 shows the time histories for a zone 7 charge, plus excess, at 400 mils elevation. These accelerometer locations can be compared to Figure 53 which shows the response at the same location for a 50 g, 2 millisecond laboratory shock in the positive vertical direction.

To obtain a value for the amplitude and duration for the initial drop test, a shock spectrum for a simple half-sine shock was used. This spectrum was compared to the field firing spectrum for the input to the fire control. Initially a 50 g, 3 millisecond pulse seemed to best fit the data. The initial drops as shown in Table II were using 50 g, 3 milliseconds on the Avco Shock Machine with inputs along the trunnion axis, vertical axis and along the horizontal fore and aft axis. The first six drop tests were along these three orthogonal axes in the positive and negative directions. Using a Q of 10 on the shock spectrum analyzer the maximax, the primary positive, and the primary negative shock spectra were computed and plotted. Essentially, the maximax shock spectra were the same as the maximum responses of the primary positive and negative spectra and showed independence from shock input direction. After the accelerometer responses for each of these six drops were compared to field firing results, a second set of 50 g, 3 millisecond drops used with a lighter fixture on the Avco Shock Machine. The results of this set indicated the need of a much more rapid shock pulse, which was not producible on the Avco Shock Machine because of the system's mass. Hence, the LAB Shock Test Machine was used to produce 50 g, 2 millisecond half-sine shock pulses for the next group of shock tests. Finally, as shown in Table II, 70 g, 2 millisecond shock data pulse on the LAB machine was obtained.

Table 1. Resonant Transmissibility from Sine Sweep Vibration Testing of the M102 Howitzer's Indirect Fire Control.

Direction of Vibration Input and Response	RESPONSE				
	Position	Location	Frequency (Hertz)	Transmissibility (db)	(Q)
Vertical ↓	3	On the Sight	35	7	2.2
			140	8	2.5
			220	10	3.
	8	Top of Mount	210	12	4.
Trunnion ↓	2	On the Sight	24	10	3.
	6	Top of Mount	24	14	5.
			800	7	2.2
	7	Base of Mount	26	19	9.
			800	19	9.
Horizontal Fore & Aft ↓	1	On the Sight	26	12	4.
	4	Base of Yoke	25	6	2.
			800	8	2.5
	5	Top of Mount	26	11	3.5
			360	5	1.8
	9	Base of Mount	25	4	1.6
			62	4	1.6
			1300	10	3.

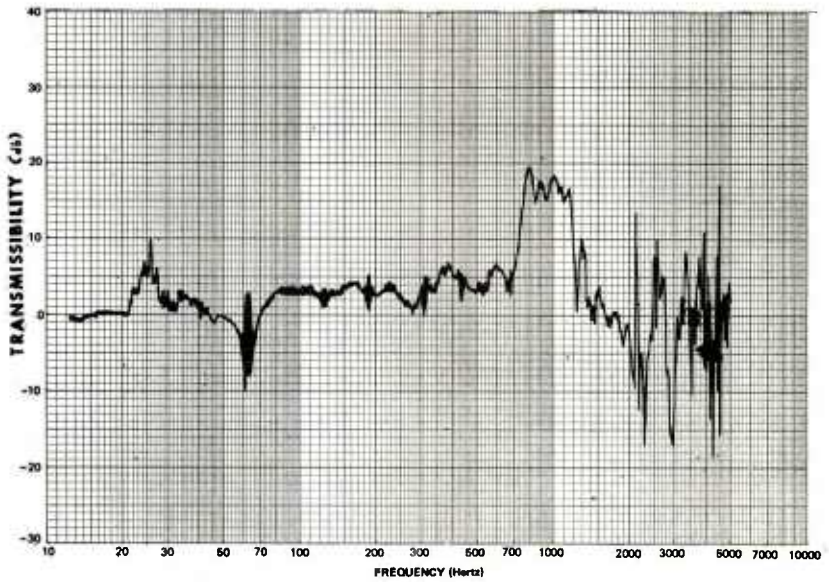


Figure 43. Vibration Response at the Base of the M102 Howitzer's M134 Mount in the Trunnion Direction.

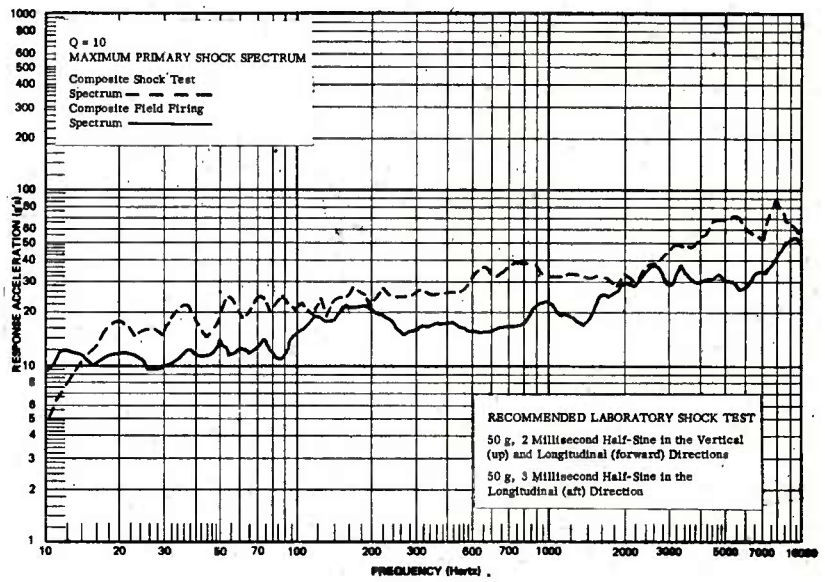


Figure 44. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Horizontal Fore and Aft Direction, (Position 1).

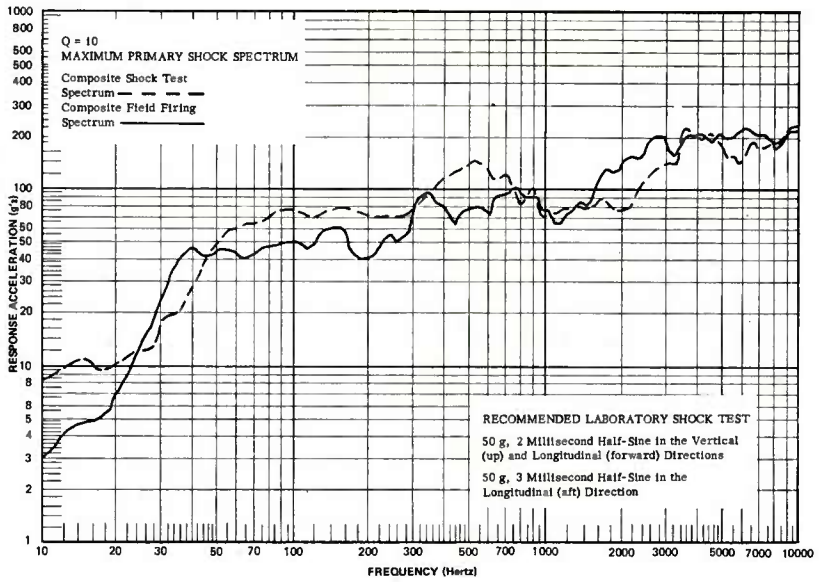


Figure 45. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Trunnion Direction, (Position 2).

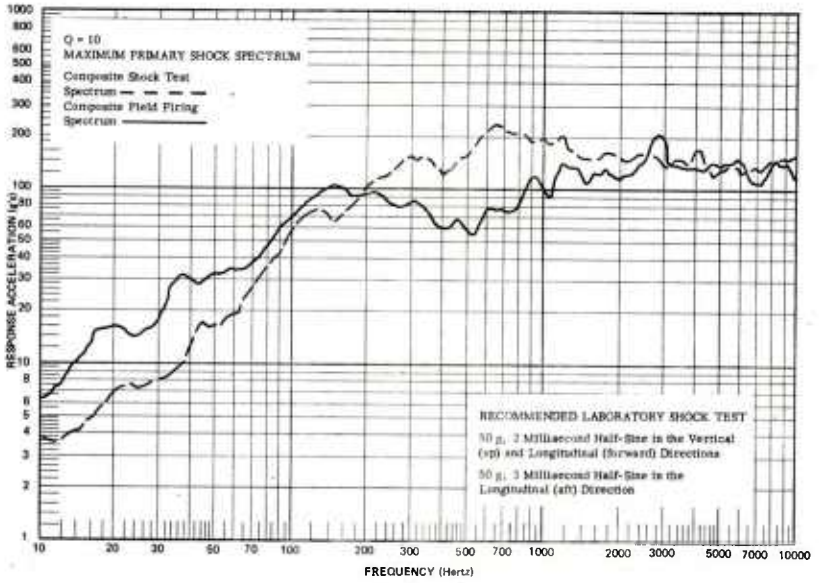


Figure 46. Comparison of Field and Recommended Laboratory Shock Response Spectra of the M102 Howitzer's M113 Panoramic Telescope in the Vertical Direction, (Position 3).

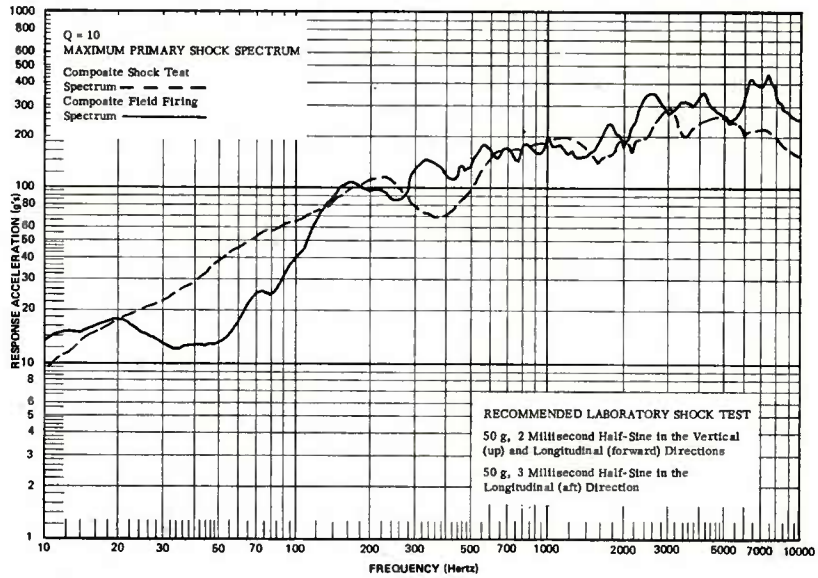


Figure 47. Comparison of Field and Recommended Laboratory Shock Response Spectra at the Middle of the M102 Howitzer's M134 Telescope Mount in the Horizontal Fore and Aft Direction, (Position 4).

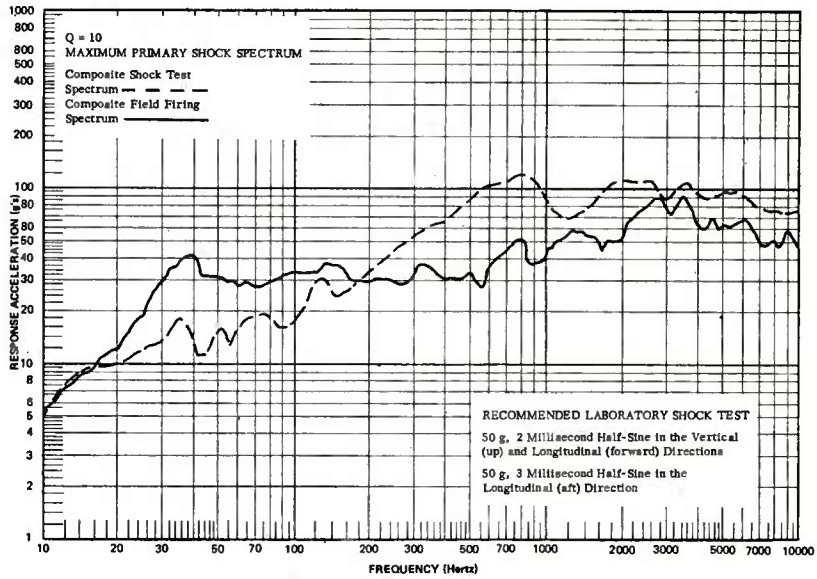


Figure 48. Comparison of Field and Recommended Laboratory Shock Response Spectra at the Top of the M102 Howitzer's M134 Telescope Mount in the Trunnion Direction, (Position 6).

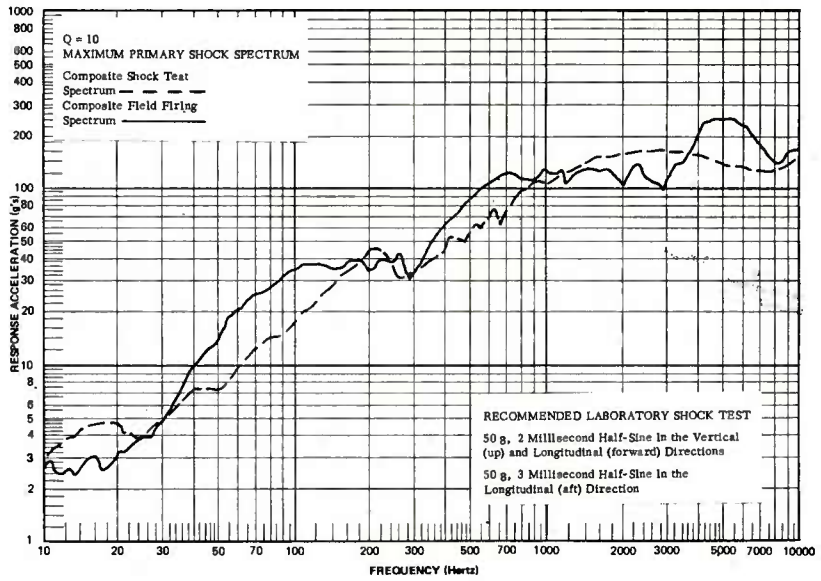


Figure 49. Comparison of Field and Recommended Laboratory Shock Response Spectra at the Base of the M102 Howitzer's M134 Telescope Mount in the Trunnion Direction, (Position 7).

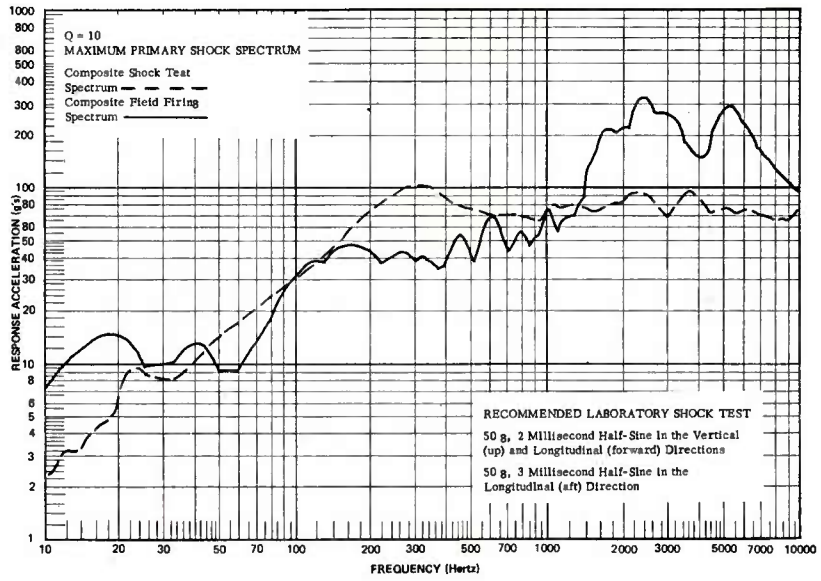


Figure 50. Comparison of Field and Recommended Laboratory Shock Response Spectra at the Top of the M102 Howitzer's M134 Telescope Mount in the Vertical Direction, (Position 8).

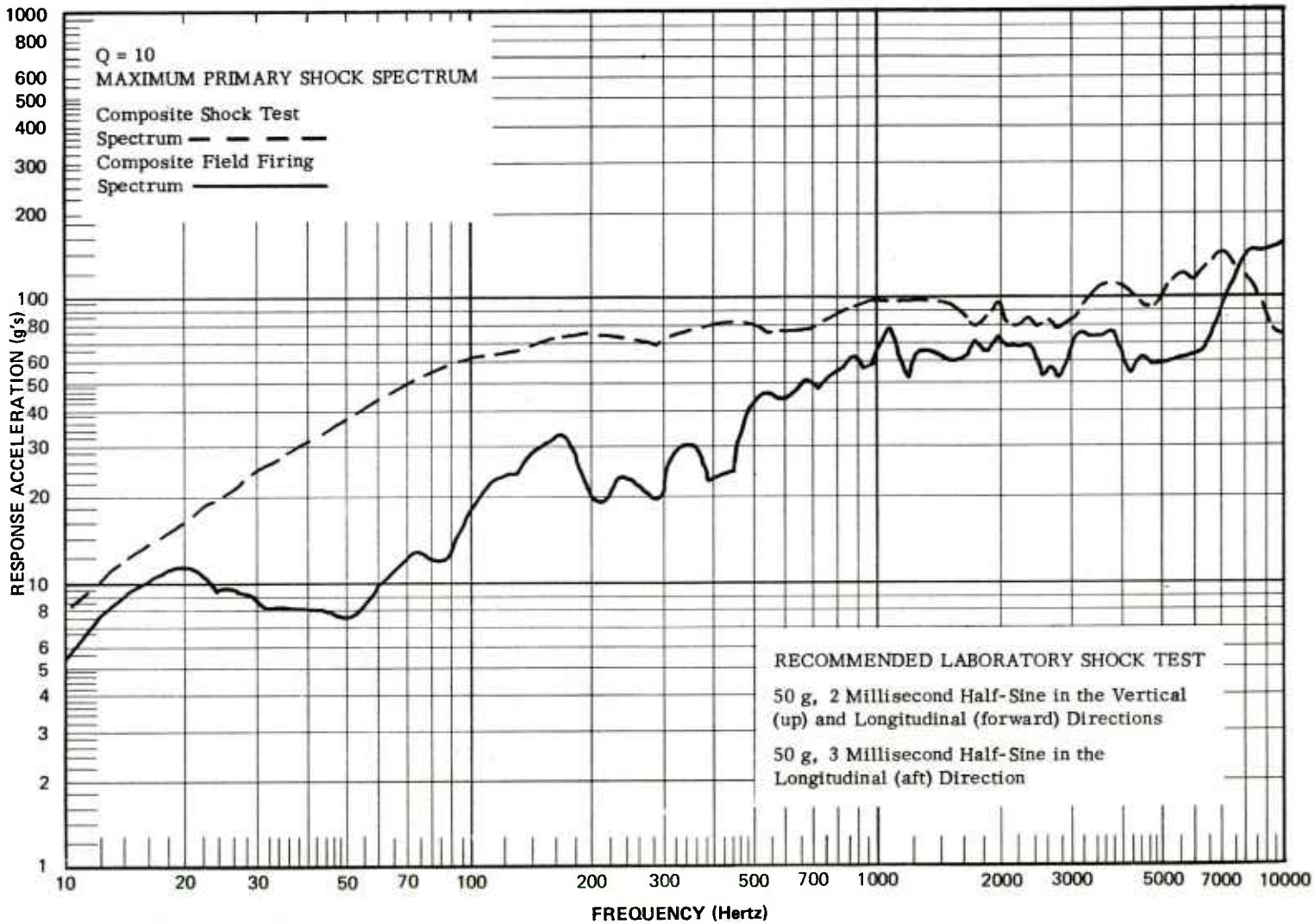


Figure 51. Comparison of Field and Recommended Laboratory Shock Response Spectra at the Base of the M102 Howitzer's M134 Telescope Mount in the Horizontal Fore and Aft Direction, (Position 9).

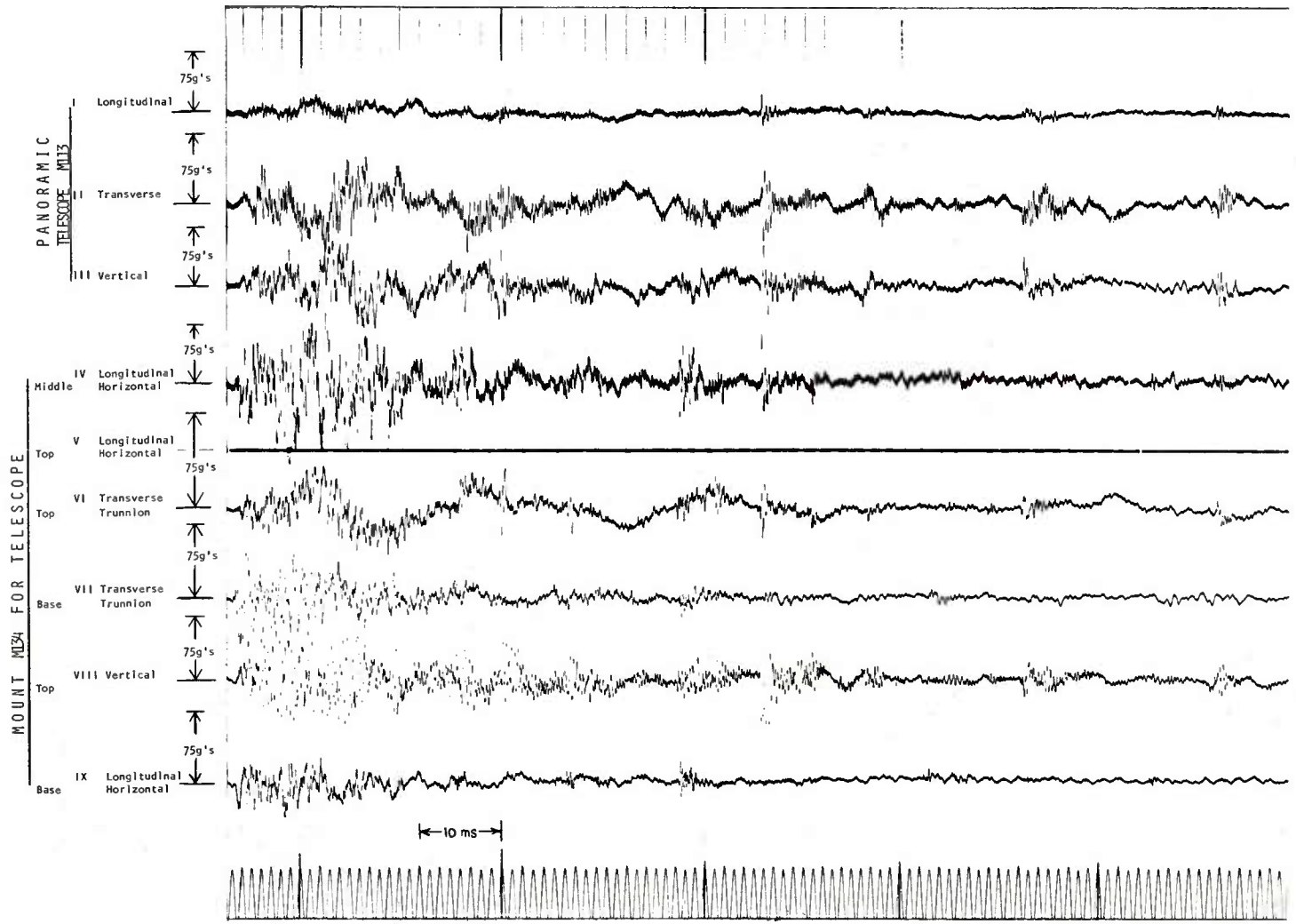


Figure 52. Acceleration Time Histories of the M102 Howitzer's Indirect Fire Control due to Field Firing Test (Round 18). Firing Conditions: Excess Charge and 400 mils Elevation.

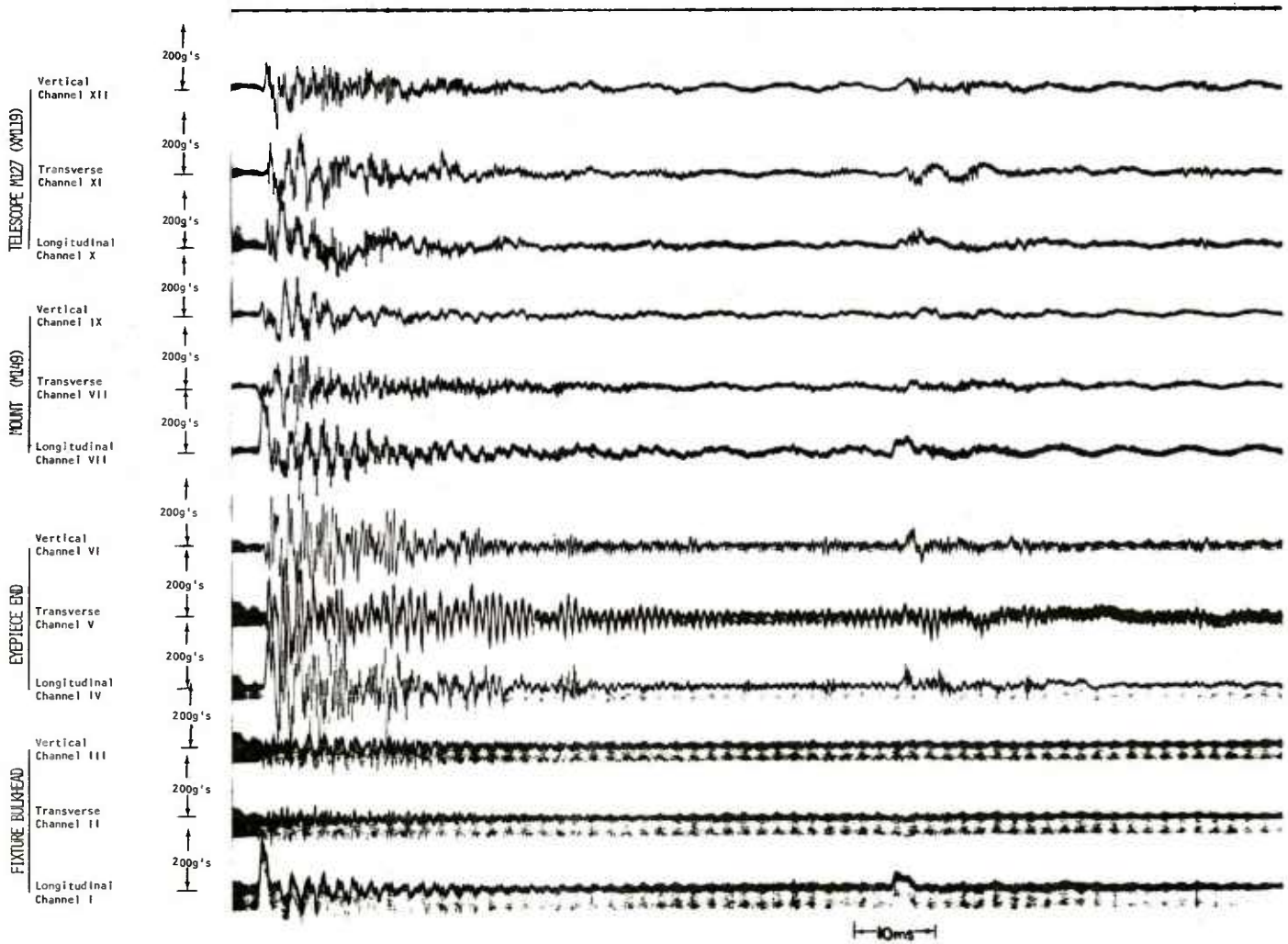


Figure 53. Acceleration Time Histories of the M102 Howitzer's Indirect Fire Control due to Laboratory Drop Test 16. Test Conditions: 50 g, 2 Milliseconds in the Vertical Upward Direction on the LAB Shock Machine.

Table II. Summary of Half-Sine Drop Tests for the M102 Howitzer's Indirect Fire Control.

Drop No.	Shock Direction	Peak Acceleration (g's)	Time Duration (Millisecond)	Shock Test	Fixture
1	Trunnion Outward	50	3	Avco	Universal Box
2	Vertical Upward				
3	Horizontal Fwd.				
4	Vertical Downward				
5	Horizontal Aft				
6	Trunnion Inward				
9	Trunnion Outward				Mounted to C 125 Fixture
10 & 11	Vertical Upward				Universal Box
12 & 13	Horizontal Fwd.				
14 & 15	Horizontal Aft				
16	Vertical Upward		2	LAB	Angle Fixture
17	Horizontal Fwd.				
18	Horizontal Aft				
23	Vertical Upward	70			

Universal Box: 6 sided aluminum plate, 23 x 26 x 23 in. high, with 1 1/4 in. thick sides and 1 1/2 in. thick top plate, (see Figure 68).

C 125 Fixture: Flat Aluminum plate with many attachment points.

Angle Fixture: Shown in Figure 42.

To select the shock test that would reproduce the response obtained from the field firing test each response shock spectra was compared with the field firing data. Table III presents the judgmental comparison of drops versus accelerometer locations. It was felt that the most significant response locations were at the base of the fire control which would represent the input to the system and response of the complete unit. The second most significant data would be the input to the sight and the least important was judged to be the response of the sight which, by the way, would also represent the input to lightweight components inside the sight such as electronics, glass prisms, etc. The method of selecting the best drops was to eliminate all drops that had an extreme overtest at any accelerometer location. This eliminated drops 2 thru 13 and drop 23, leaving drops 1 and 15 to 18. Drop 16 was good for position 9 and fair for positions 7, 6 and 2, not bad for positions 8 and 3 and a slight undertest for position 1. By incorporating drop 15, we could improve the shock spectrum for position 2, and also pick up a pretty good representation for position 4. These two drops, 15 and 16, constitute a good test and reduce the testing from six directions to a vertical up test of 50 g, 2 milliseconds and a test along the horizontal axis in the forward direction of 50 g, 3 milliseconds. An additional improvement could be realized by adding drop 17, which is a 50 g, 2 millisecond shock test along the horizontal axis in the aft direction. This drop test would improve the response of position 3 from a not bad representation, to a fair representation but would also create a slight overtest for position 1. This overtest was considered insignificant because the response acceleration levels of 20 and 30 g's was so low, plus position 1 represented the response of a component inside the sight. The advantage of improving the simulation of position 3 plus the added facts that the shock pulse and the fixturing respectively are the same for the horizontal testing in the forward direction, make this shock test an ideal one to add to the specification.

One note of interest is the assumption made earlier as to the Q's of the system or the amount of damping assumed for the computation of the shock spectrum. Since the same Q is used to analyze the shock test data and the field firing data, the effect of the Q selected is diminished to a great extent. This is not true when there is a considerable ringing or sinusoidal response in the test data because, for this situation, the Q would amplify the ringing that is present in the original test data and create a different response for a different value of Q assumed. For the data being analyzed, this assumption of the structural damping or Q does play some significance since the response of the fire control due to the weapon firing has a great deal of sinusoidal ringing and the laboratory test does not have the same degree of structural response. To a great extent, the ringing of the fire control is due to the fire control itself and not due to the input of the base of the weapon. The acceleration time history for the sight unit is similar for the laboratory test and the field firing. There is a difference, however, down at the base of the fire control where the laboratory time history looks more like a simple pulse than the firing.

When correlating laboratory spectra with field spectra, a great deal of judgment is involved since two complex curves are being compared. To try to evaluate

Table III. Comparison of Field and Laboratory Shock Response Spectra of the M102 Howitzer's Indirect Fire Control using the Maximum of the Primary Positive and Negative Spectra for Q = 10.

Drop No.	Shock Direction	INPUT TO MOUNT			INPUT TO SIGHT		RESPONSE OF SIGHT		
		⑦ Trunnion Direction	⑧ Vertical Direction	⑨ Horizontal Direction	④ Horizontal Direction	⑥ Trunnion Direction	① Horizontal Direction	② Trunnion Direction	③ Vertical Direction
1	Trunnion Outward	O.T.	U.T.	U.T.	U.T.	O.T.	Poor	Good	Good
2	Vertical Upward	U.T.	E.O.T.	U.T.	U.T.	Good	U.T.	Fair	Good
3	Horizontal Fwd.	U.T.	U.T.	E.O.T.	Fair	U.T.	Fair	U.T.	U.T.
4	Vertical Downward	U.T.	E.O.T.	U.T.	U.T.	Fair	U.T.	Fair	Good
5	Horizontal Aft	U.T.	U.T.	E.O.T.	Good	U.T.	E.O.T.	Good	N.G.
6	Trunnion Inward	O.T.	Poor	U.T.	U.T.	E.O.T.	U.T.	Good	Fair
9	Trunnion Outward	O.T.	U.T.	U.T.	U.T.	E.O.T.	U.T.	Good	Good
10 & 11	Vertical Upward	U.T.	E.O.T.	U.T.	U.T.	Fair	N.G.	Fair	Good
12 & 13	Horizontal Fwd.	U.T.	U.T.	E.O.T.	Fair	U.T.	O.T.	Fair	U.T.
14 & 15	Horizontal Aft	U.T.	U.T.	S.O.T.	Good	U.T.	/	Good	Poor
16	Vertical Upward	Fair	Fair	Good	U.T.	Fair	S.O.T.	Fair	Fair
17	Horizontal Fwd.	Fair	S.U.T.	O.T.	U.T.	U.T.	Good	U.T.	Fair
18	Horizontal Aft	Fair	U.T.	Good	U.T.	U.T.	Fair	U.T.	U.T.
23	Vertical Upward	Fair	E.O.T.	Fair	S.U.T.	E.O.T.	O.T.	Good	Fair

LEGEND
E.O.T. Extreme Over Test
O.T. Over Test
S.O.T. Slight Over Test
E.U.T. Extreme Under Test
U.T. Under Test
S.U.T. Slight Under Test
Poor Slight Over and Under Test
N.G. Extreme Over and Under Test

the degree of fit, judgmental words were required, such as: good, fair, or poor. Additionally, it was important to know if the field test was more severe or less severe than the laboratory shock test, which simulates that composite field firing condition. To have a laboratory shock test that is less severe at some locations than the field firing condition is acceptable as long as we have a series of drops that will bring the response of all twelve accelerometer locations close to that of the field firing condition.

Recommended Laboratory Shock Test

The recommended laboratory shock test for the M102 Indirect Fire Control is to shock the unit six times along each of the three directions for a total of eighteen shocks. For the vertical (up), and the horizontal (forward) directions, the recommended shock test is 50 g, 2 millisecond half-sine. For the horizontal (aft) direction, the recommended shock test is 50 g, 3 milliseconds. No testing is required for the other three directions. The elimination of the trunnion (outward) shock direction, where the fire control is being pulled away from the fixture, represents a substantial savings in fixturing, since a box type fixture, from which to hang the Fire Control, was necessary for this test.

Section 4

M551 SHERIDAN VEHICLE

The M551 Sheridan vehicle is a full-tracked, lightweight, amphibious, air-droppable armored vehicle, designed for both reconnaissance and assault operations. Figure 54 shows the Sheridan Vehicle, its M127 Telescope and M149 Mount, and the XM44 Periscope. The optical fire control system was tested in a manner similar to that which was described earlier.

Laboratory Testing and Results of the M127 Telescope and M149 Mount

Figure 55 shows the M127 Telescope inside the shock test fixture. The telescope was mounted to the fixture in the same manner as it is mounted in the vehicle. This figure also shows the locations of the twelve accelerometers. Six of the accelerometers are at the same location as for the field firing test[3] and were used in the selection of a suitable shock test. The other six locations were three on the fixture and three on the telescope's eyepiece. The response of the fixture accelerometers were sufficiently similar to the response of the Sheridan's bulkhead accelerometers to preclude further pursuit for this report.

The telescope mounted inside the shock test fixture is shown in Figure 56. The fixture is shown on the LAB Shock Machine ready for a longitudinal shock and a positive vertical shock in the up direction. Since the telescope had a record of previous laboratory failures, the maximum drop of 2 1/2 inches for an acceleration of 300 g's, was approached with extreme caution. Each examination after testing indicated no visible damage to the telescope.

Typical acceleration time histories of field and laboratory shocks are shown for comparison in Figures 57 and 58 respectively. In both figures, there is a lack of high frequency in the acceleration time histories for the response of the telescope as compared to those for the mount. This indicates that most of the high frequency response is absorbed in the telescope joints. The increased amplitude for the three accelerometers on the eyepiece indicated the effect of a long lever arm with a single support bracket.

In the vibration tests, which swept the input from 10 to 5,000 Hertz, the eyepiece had some low level multi-resonant points throughout the frequency range. Figures 50 to 61 show three typical response curves for the mount. In these curves the response is in the same direction as the input. Since the Telescope Mount's

[3]Wiland, James H., "Firing Shock Measurements on the M551 Sheridan Fire Control System," Frankford Arsenal Test Report T72-10-1, June 1972.

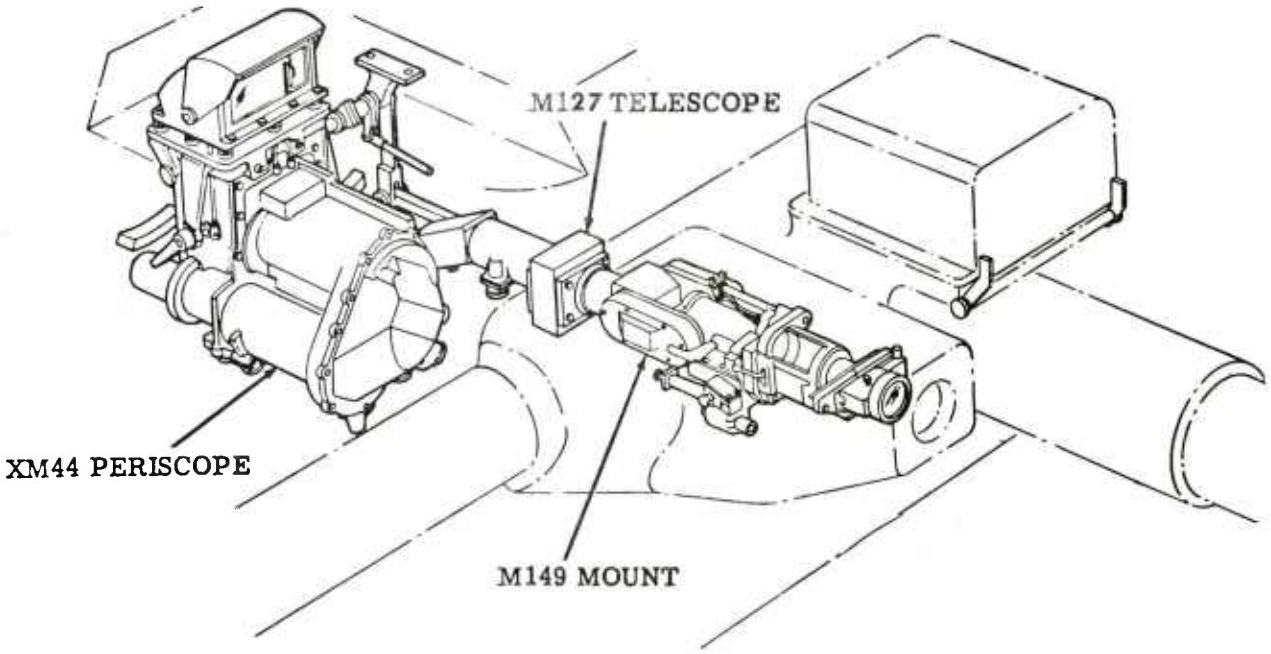


Figure 54. M551 Sheridan Vehicle and Optical Fire Control Instruments.

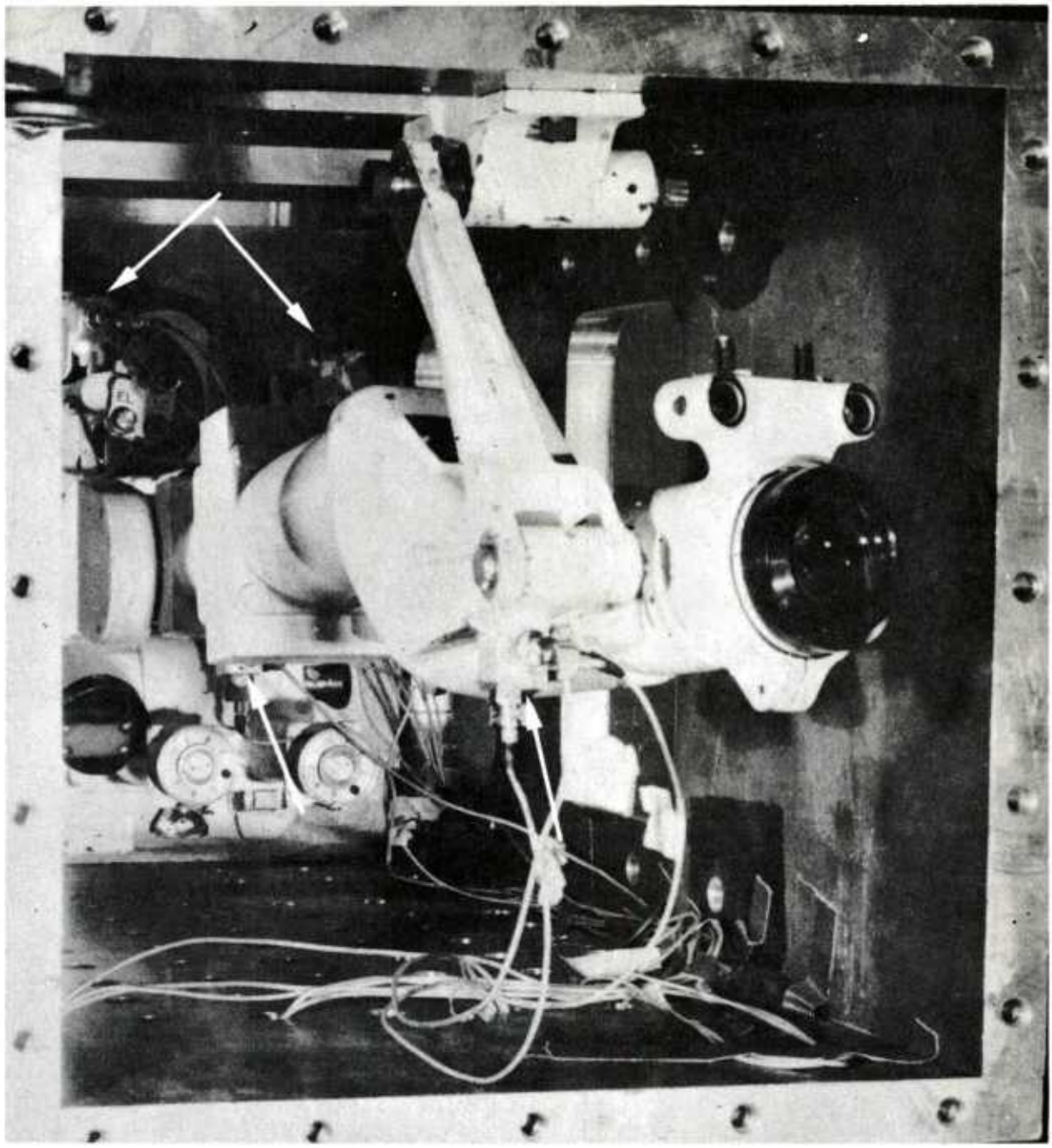
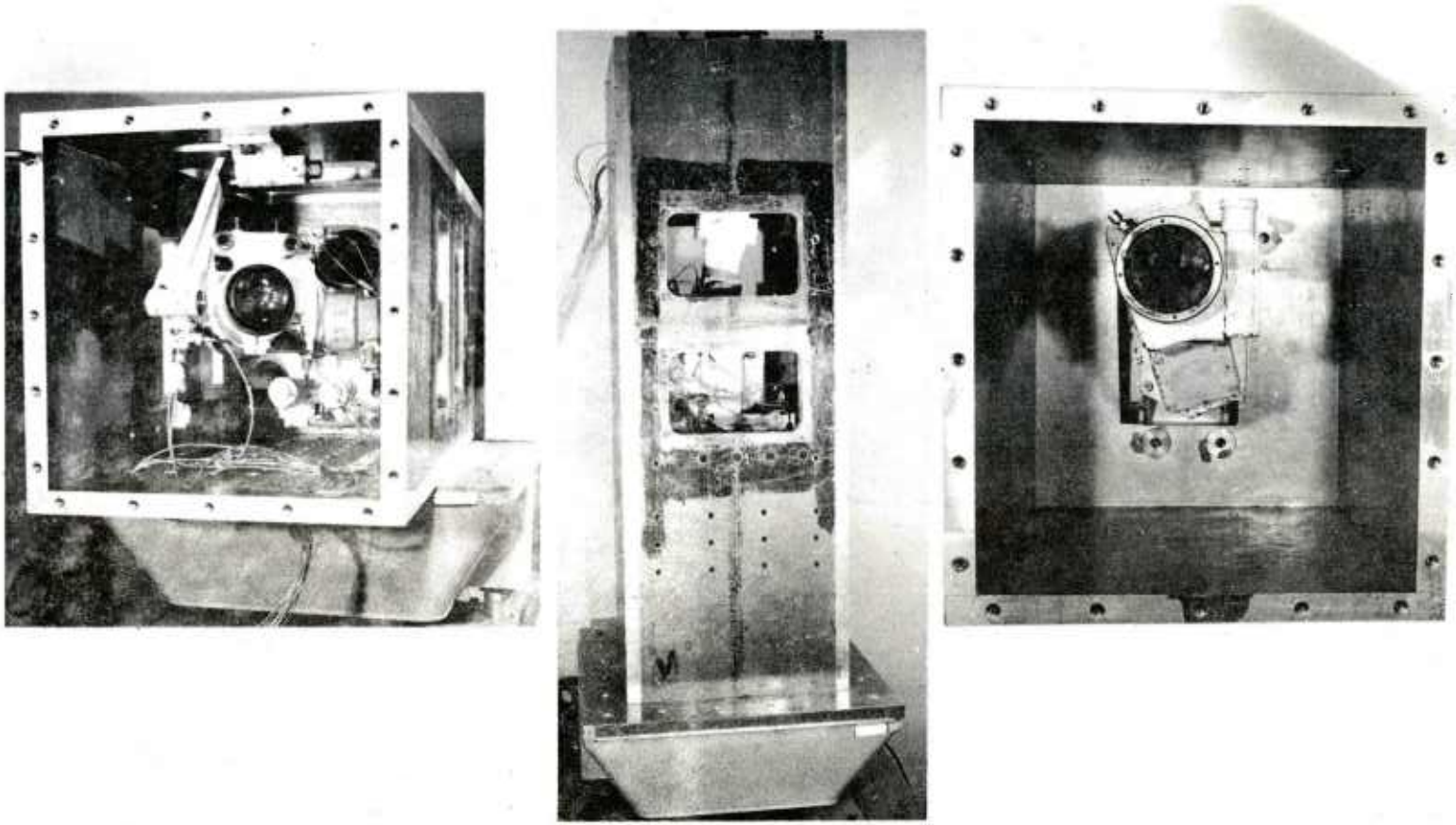


Figure 55. Laboratory Accelerometer Locations on the M551 Sheridan's M127 Telescope, its M149 Mount, and its Fixture.

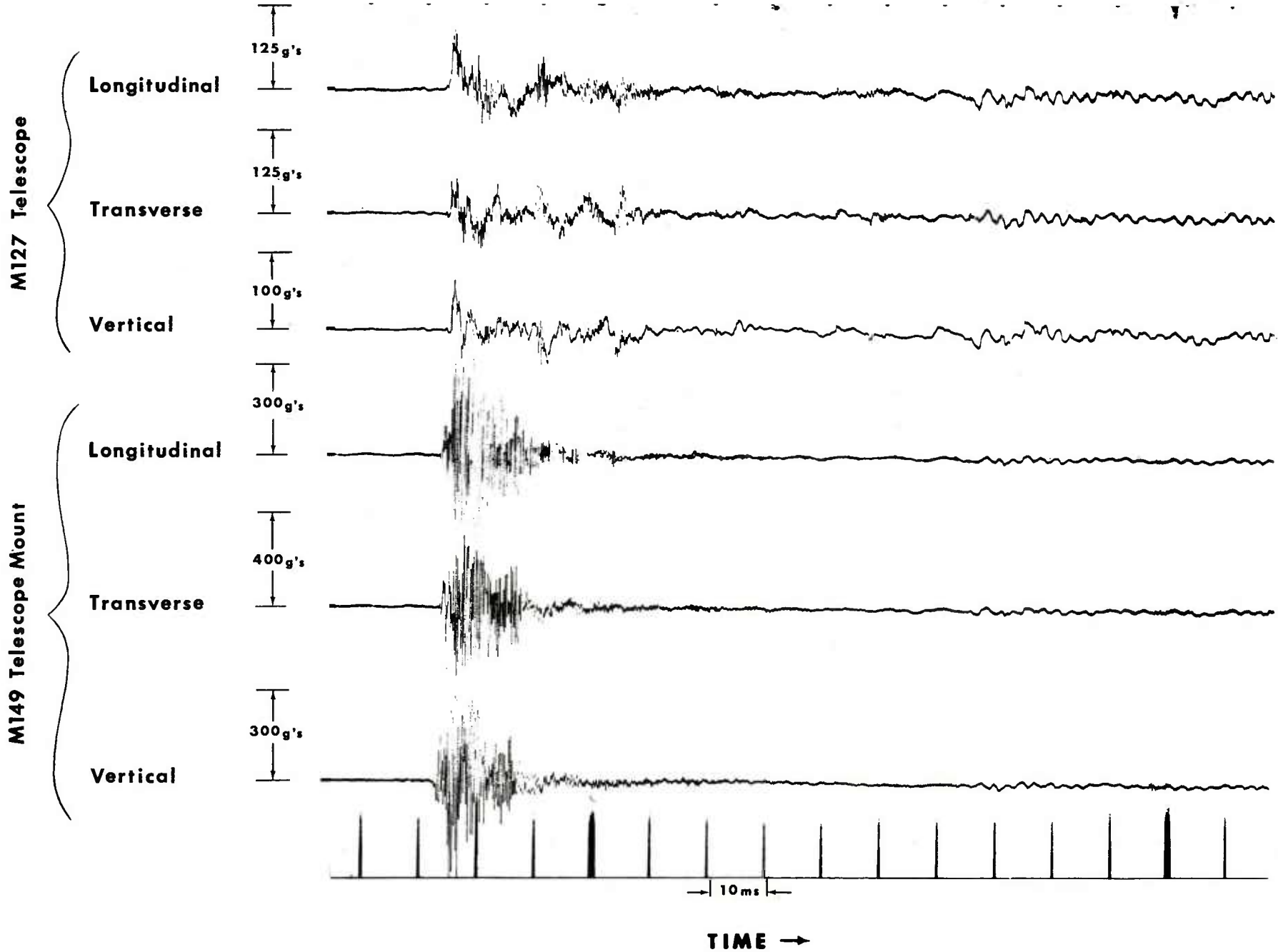


Telescope End

Side

Mount View

Figure 56. Positioning of the M551 Sheridan's M127 Telescope, M149 Mount and Fixture, on the LAB Shock Machine.


M127 Telescope
Longitudinal
125g's
Transverse
125g's
Vertical
100g's
M149 Telescope Mount
Longitudinal
300g's
Transverse
400g's
Vertical
300g's
10ms
TIME →

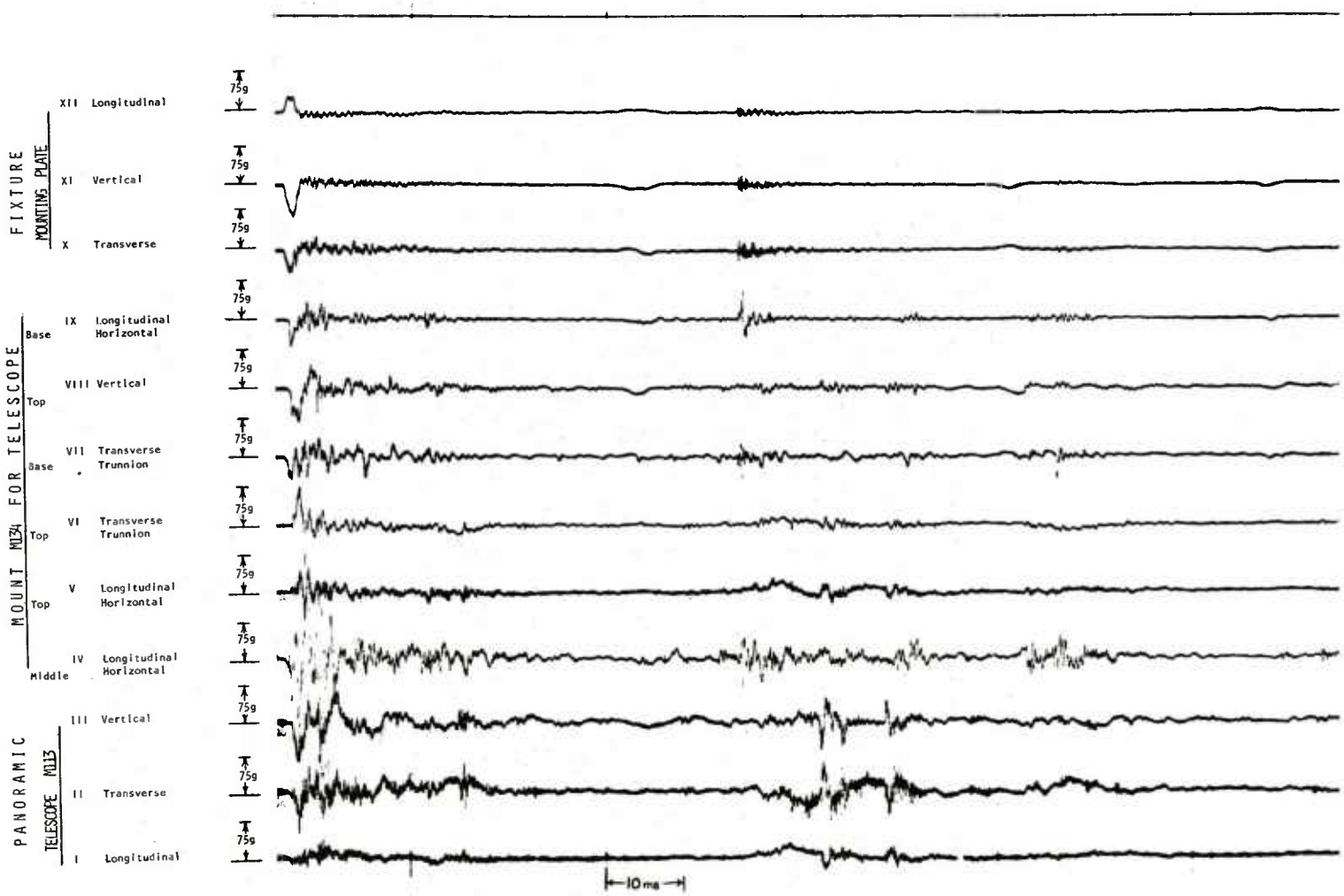


Figure 58. Typical Laboratory Acceleration Time Histories of the M551 Sheridan's M127 Telescope and M149 Mount due to a 150 g, 1 Millisecond Positive Vertical Shock.

response was the only curve to reach a transmissibility of 10 at 180 Hertz and exceed 10 at 750 Hertz, a value of 10 was assumed for the shock spectrum analysis. The massiveness of the telescope, mount, and fixture caused the complete system to rock above 1,000 Hertz, which made data collection difficult.

Within the acceleration test range of 50 to 300 g's, the primary (+) and (−) shock spectrum analyses were chosen as the most informative for laboratory to field comparison. Laboratory induced half-sine, 100 g, 1 millisecond shock pulses give good simulation of field results for frequencies above 800 Hertz. Furthermore, in this region a single longitudinal 100 g drop is sufficient to adequately simulate all tested orthogonal directions. Increased drop height did not proportionally increase the average high (i.e. above 800 Hertz) frequency range. Below 800 Hertz no single unidirectional test simulated all three directions.

The best overall imitation of the field shock by laboratory testing was rendered by a 150 g, 1 millisecond half-sine pulse on the LAB Shock Machine. Figures 62 through 67 show respectively the vertical, transverse and longitudinal laboratory shocks compared to those from the field. At frequencies above 2,000 Hertz, the high g level field response from the telescope mount was caused by exceeding the flat range of those accelerometers. The plotted field data are the composites of maximum g levels from the primary, (+) and (−) shock spectrum analyses, which were obtained from earlier field studies[3] for each direction and position. Although the curves show significant overtesting at various frequencies, this 150 g, 1 millisecond half-sine pulse is a good simulation. This overtesting is acceptable since no damage occurred even when a 300 g, 1 millisecond shock was applied.

A single 150 g, 1 millisecond shock in each orthogonal direction can adequately simulate the field data and provide as much new data as the standard six tests. An examination of the curves in Figures 62 through 67 for the telescope and its mount reveal the following: the primary (+) and (−) curves for each shock are essentially the same for frequencies less than 800 Hertz and are generally not significantly different above 800 Hertz. For the vertical and transverse directions, reversing the direction of the applied shock pulse generally exchanged positions of the primary (+) and (−) curves. Since the design of the telescope retaining ring and the large radius of curvature of the single vertical support bracket at the eyepiece made testing the telescope with a positive longitudinal shock, ill advised, this direction was not attempted.

Recommended Laboratory Shock Test

The recommended laboratory shock test for the M127 Telescope and M149 Mount is to shock the unit six times along each of the three orthogonal axes for a total of eighteen shocks. The recommended shock test is a 150 g, 1 millisecond half-sine shock, applied in the negative vertical direction (downward), the negative

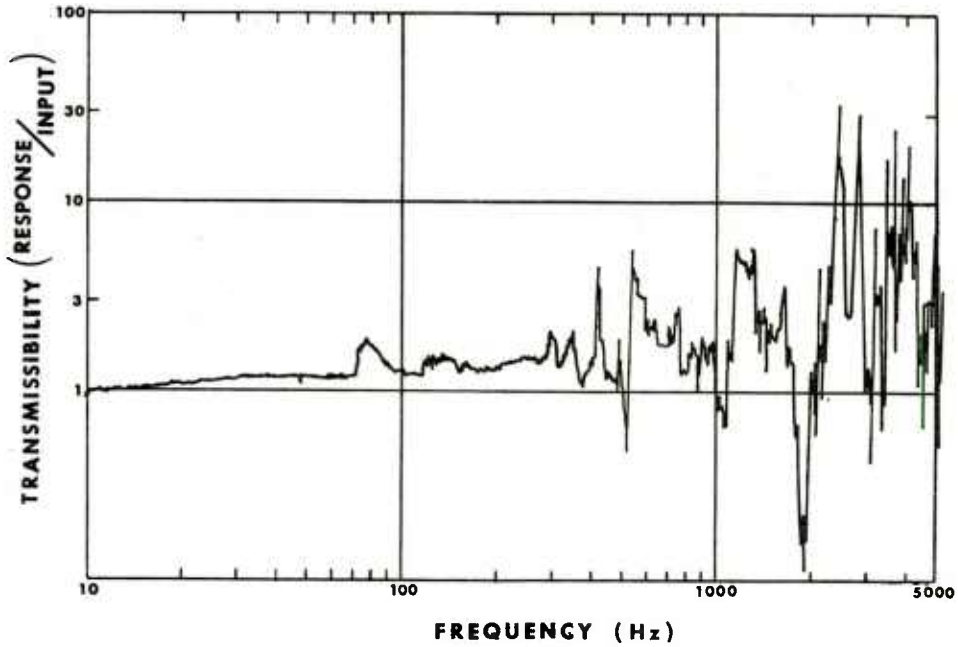


Figure 59. Vibration Response of the M551 Sheridan's M149 Mount in the Vertical Direction.

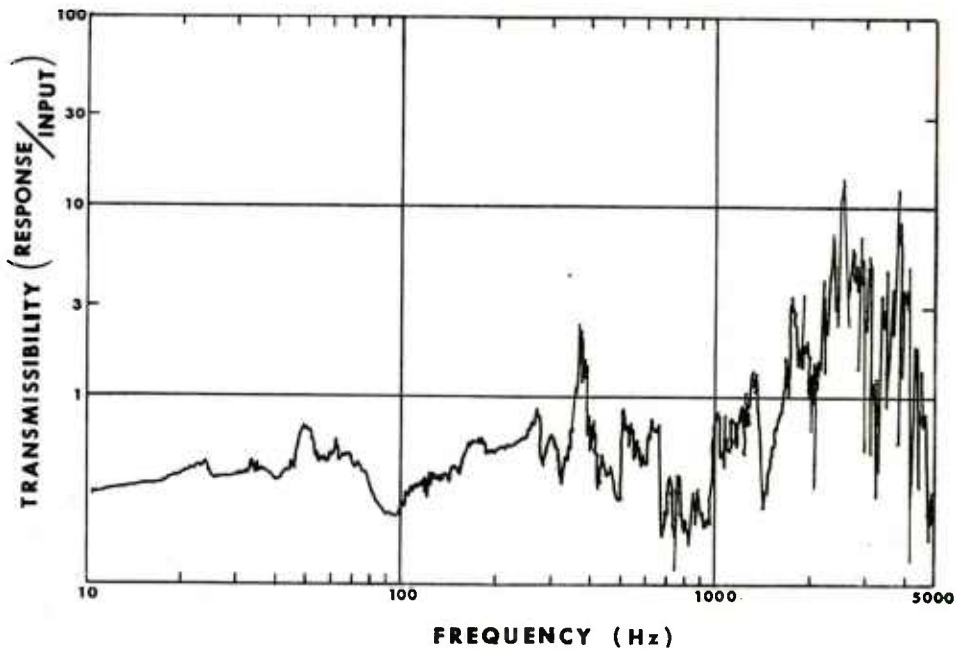


Figure 60. Vibration Response of the M551 Sheridan's M149 Mount in the Transverse Direction.

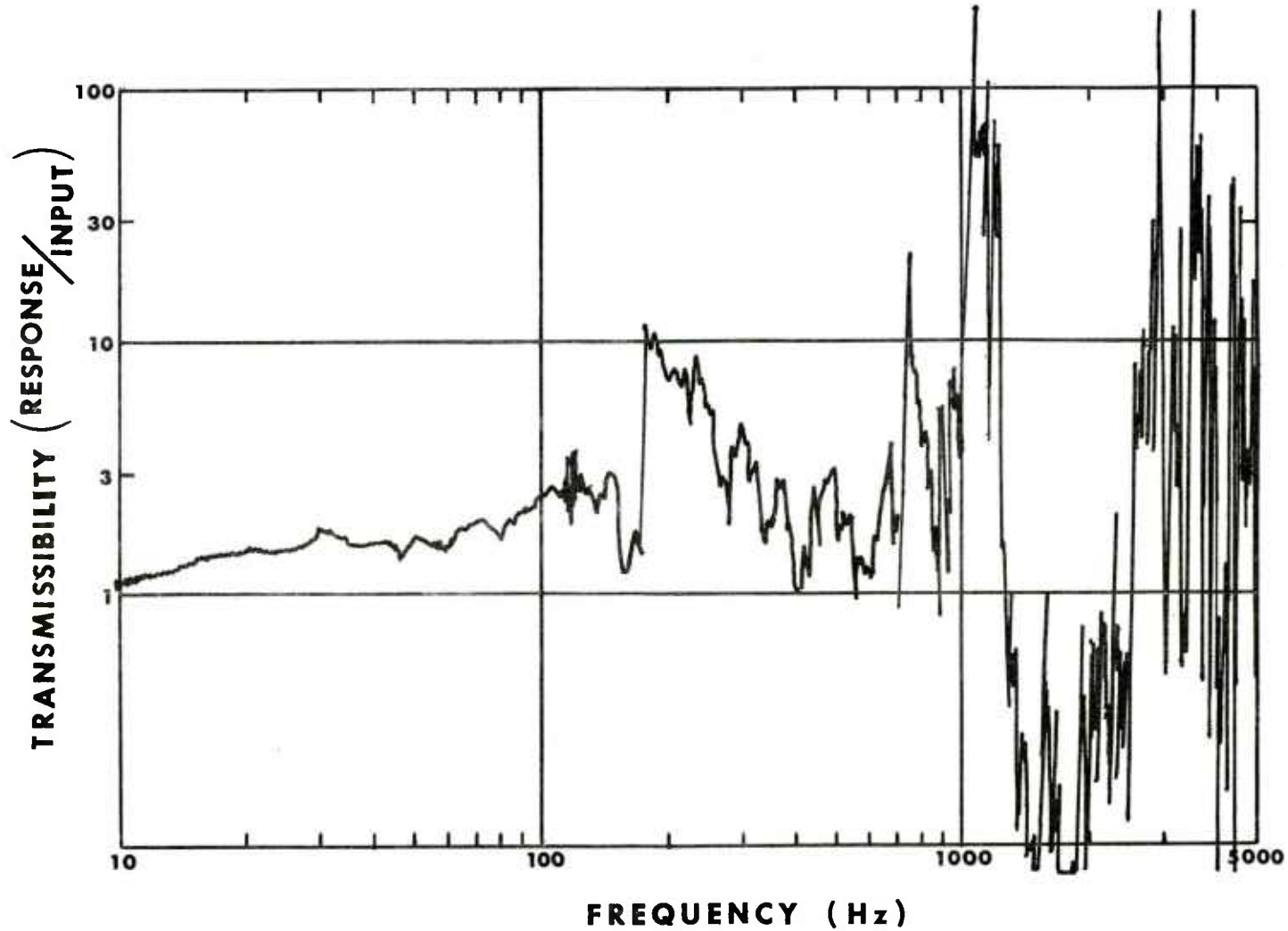


Figure 61. Vibration Response of the M551 Sheridan's M149 Mount in the Longitudinal Direction.

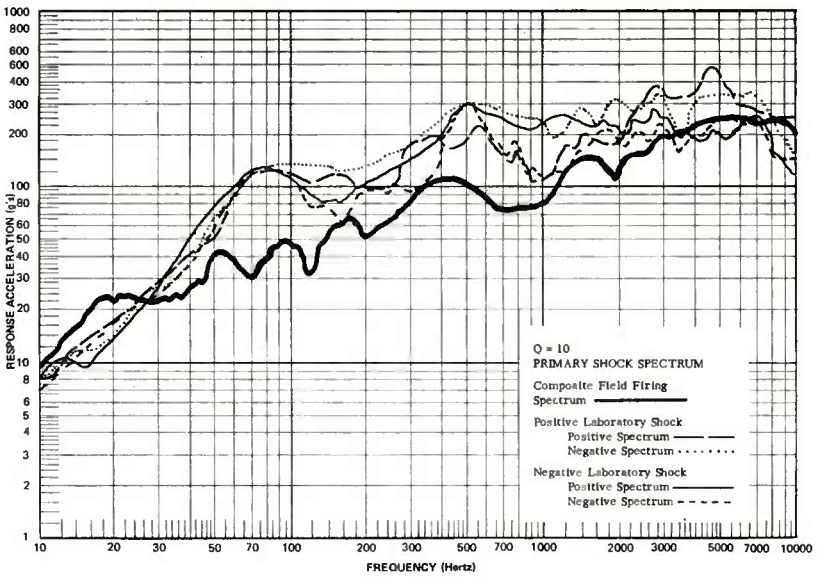


Figure 62. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M127 Telescope in the Vertical Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Vertical Direction.

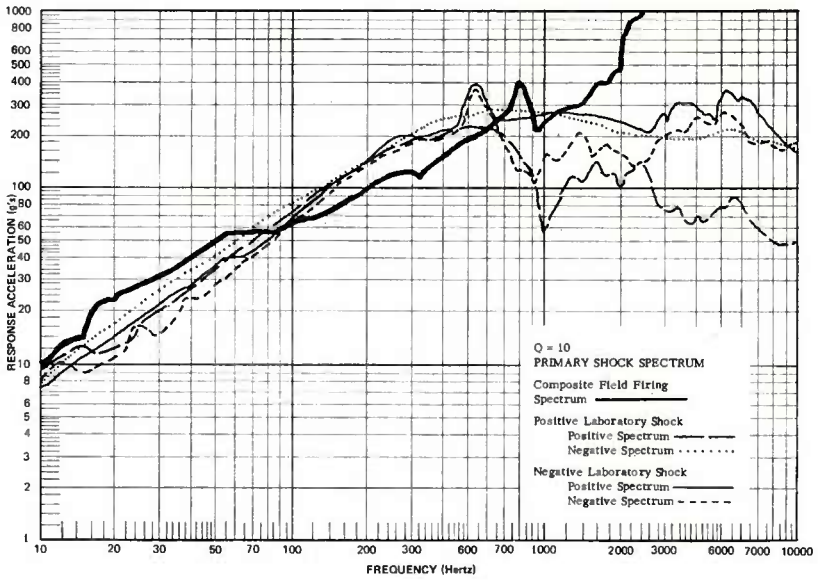


Figure 63. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Vertical Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Vertical Direction.

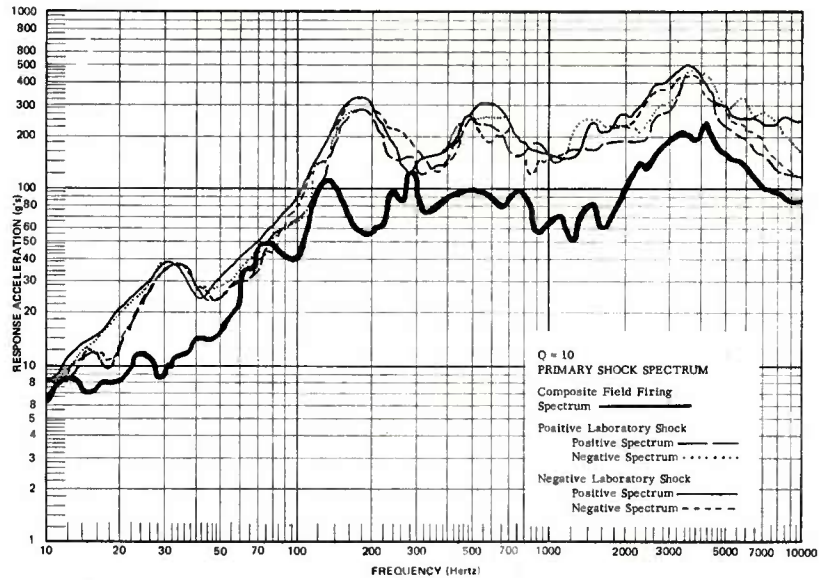


Figure 64. Comparison of Field and Laboratory Shock Response of the M551 Sheridan's M127 Telescope in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.

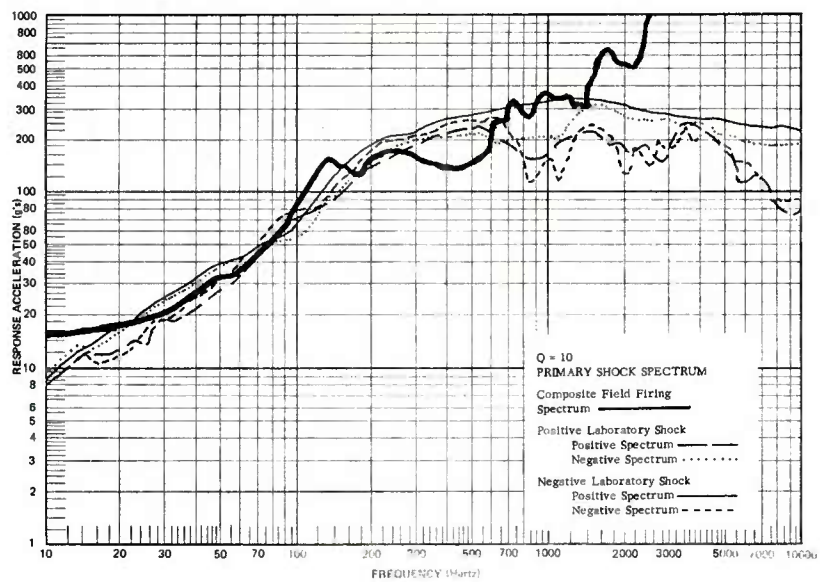


Figure 65. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Transverse Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Transverse Direction.

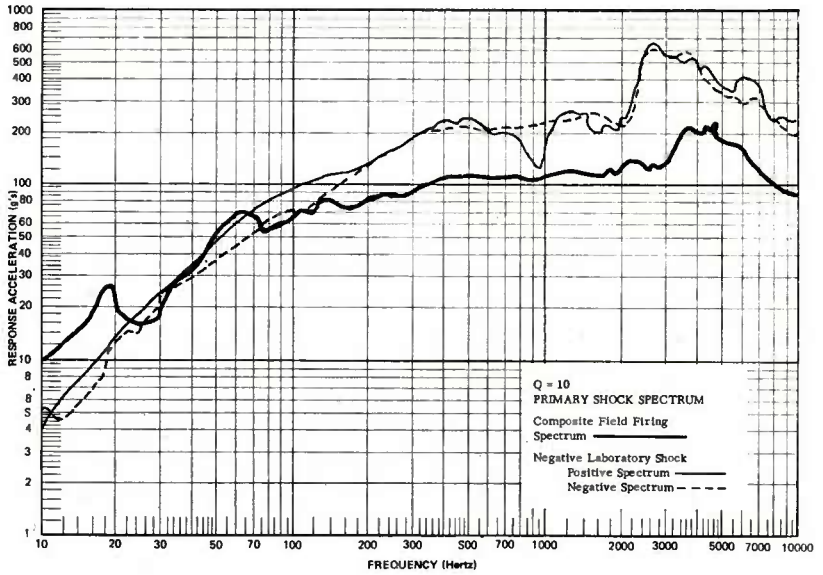


Figure 66. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M127 Telescope in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.

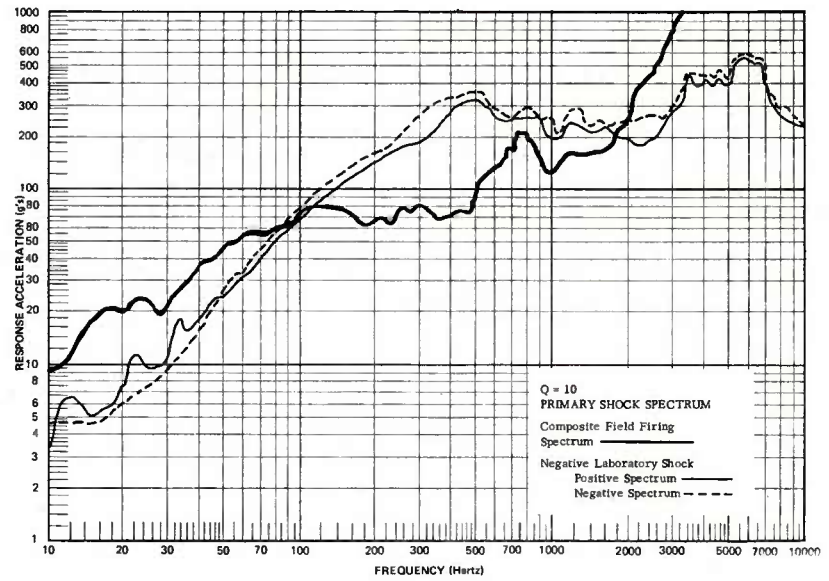


Figure 67. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's M149 Mount in the Longitudinal Direction due to a 150 g, 1 Millisecond Half-Sine Shock in the Longitudinal Direction.

longitudinal direction (aft) and the negative transverse direction (facing forward, the applied shock going from right to left).

Laboratory Testing and Results of the XM44 Periscope

The Sheridan XM44 Periscope, mounted for a positive longitudinal shock on the Avco Shock Machine is shown in Figure 68. The periscope was mounted to the test fixture in the same manner as it was mounted in the Sheridan Vehicle. Three accelerometers were mounted on the periscope and three accelerometers were mounted on the mounting plate.

A half-sine, 50 g, 3 millisecond pulse on the Avco Shock Machine produces the best overall simulation of field studies.[3] Unfortunately, these simulations were usually not as good as those of the telescope because of the frequent significant over-testing at frequencies less than 200 Hertz. Since the g level is so much lower and this system is less fragile, the chance laboratory induced erroneous failure at 50 g's is negligible.

A maximum of four shock tests, as indicated by Figures 69 through 74, are necessary to fully test this item. The consistent g level difference in the primary (+) and (−) shock spectra and the undertesting of the periscope show that the opposite vertical test as shown in Figure 69 may be necessary. The Avco fixture box precluded making negative vertical drops. Figures 71 through 74 show the negative drops are better field test simulations.

Recommended Laboratory Shock Test

The recommended laboratory shock test for the XM44 Periscope is to shock the unit six times along each of the three orthogonal axes for a total of eighteen shocks. The recommended shock test is a 50 g, 3 millisecond half-sine shock, applied in the positive and negative vertical directions, the negative longitudinal direction (aft), and the negative transverse direction (facing forward, the applied shock going from right to left).

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[3]Wiland, James H., "Firing Shock Measurements on the M551 Sheridan Fire Control System," Frankford Arsenal Test Report T72-10-1, June 1972.

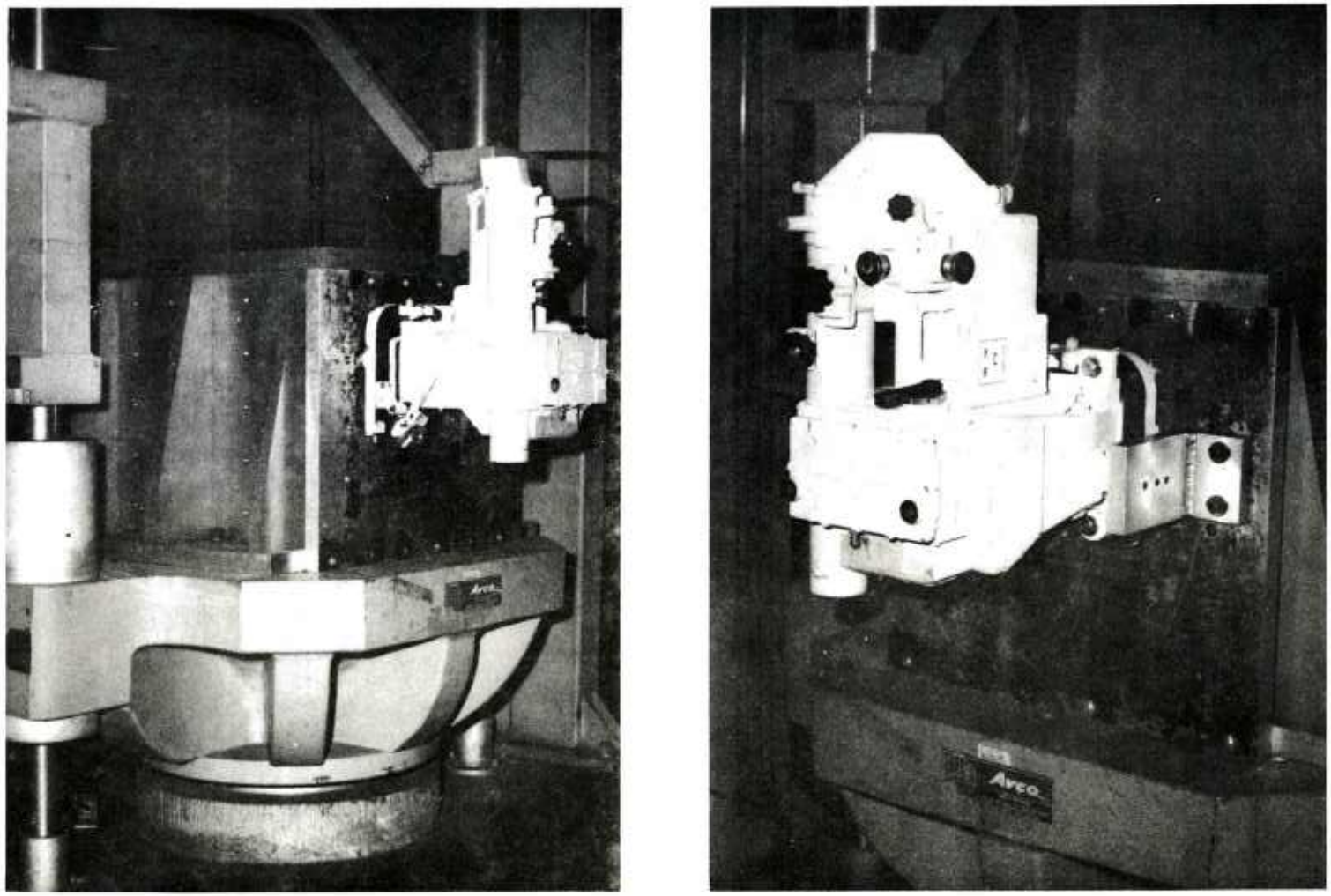

Figure 68. The M551 Sheridan's XM44 Periscope Mounted on the Avco Shock Machine Positioned for a Positive Longitudinal Shock.

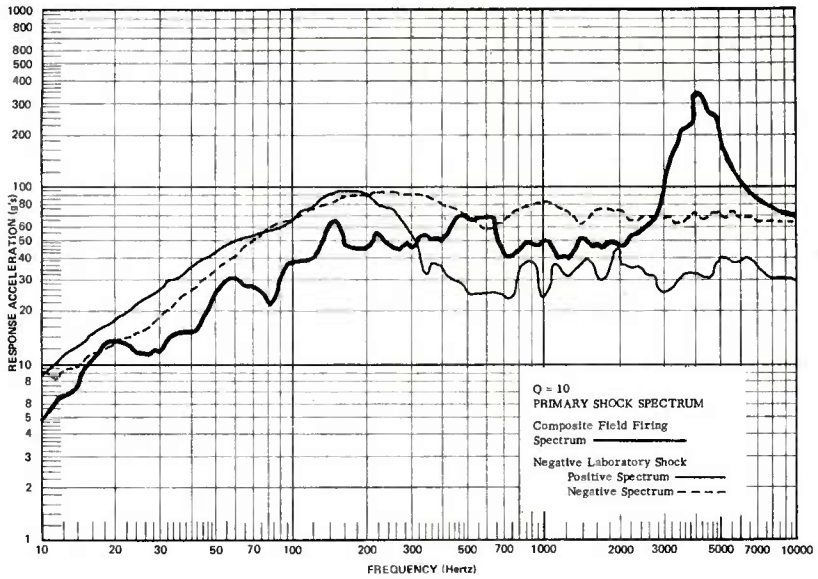

Figure 69. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Vertical Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Vertical Direction.

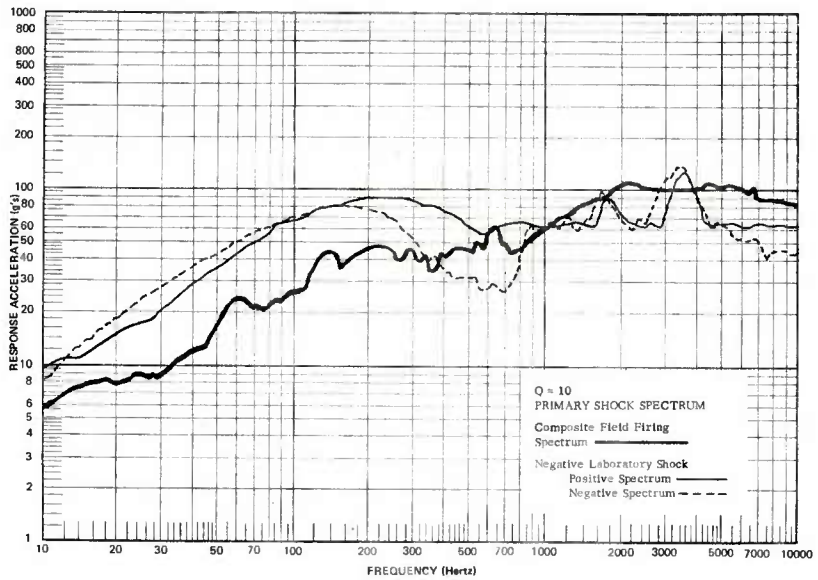

Figure 70. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Vertical Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Vertical Direction.

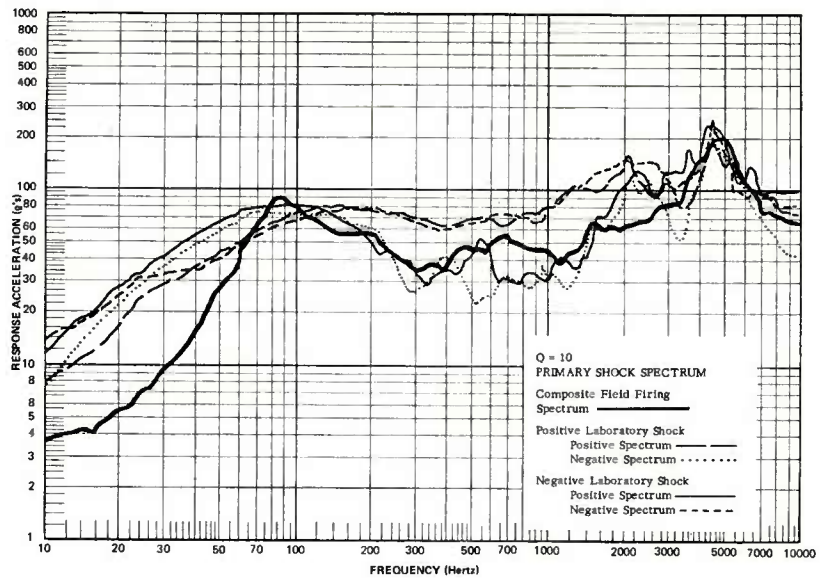

Figure 71. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Transverse Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Transverse Direction.

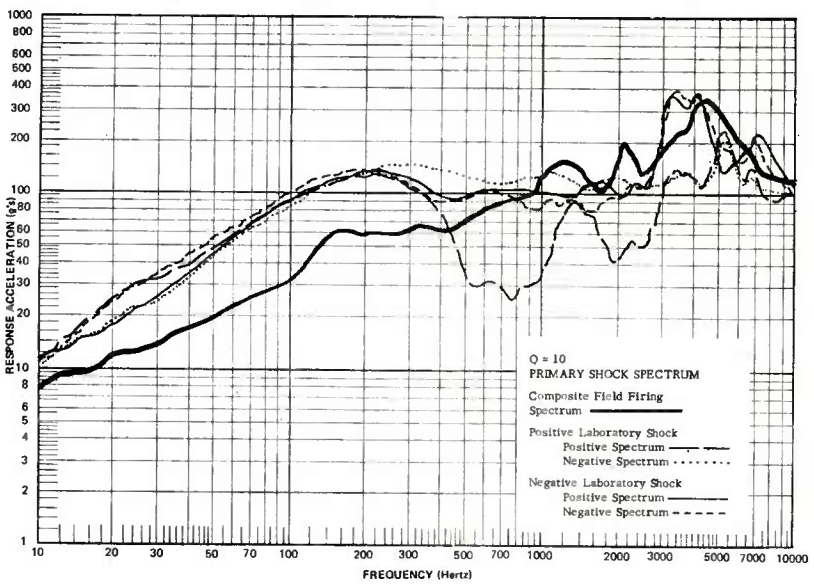

Figure 72. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Transverse Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Transverse Direction.

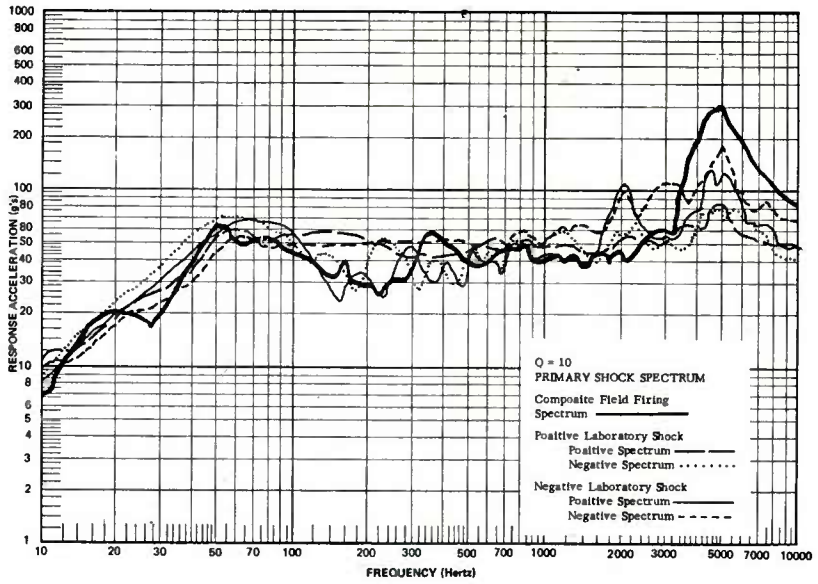

Figure 73. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's XM44 Periscope in the Longitudinal Direction due to a 50 g, 3 Millisecond Half-Sine in the Longitudinal Direction.

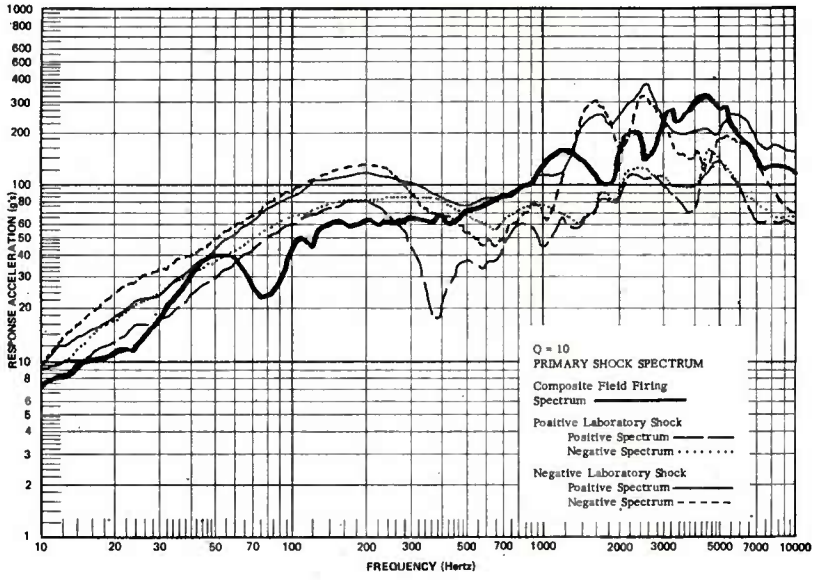

Figure 74. Comparison of Field and Laboratory Shock Response Spectra of the M551 Sheridan's Periscope Mount in the Longitudinal Direction due to a 50 g, 3 Millisecond Half-Sine Shock in the Longiduinal Direction.

Section 5

DEVELOPING A SHOCK TEST TO SIMULATE THE EFFECTS OF FIRING MANY ROUNDS

At present, the fire control instruments are shock tested a total of eighteen times which is three shocks in each of the three orthogonal directions and three shocks along the same axis in the negative direction. In the field, the fire control receives as many as ten to twenty thousand shocks. The fire control must be able to withstand the field service shocks for the life of the weapon. Some of the problems encountered in developing laboratory test specifications to determine if the fire control system will survive for the life of the weapon are presented herein.

The problems encountered fell into two general categories which to a large extent overlap one another. The first category is concerned with increasing the level of the shock to take into consideration the fatigue level of the material. The second category is concerned with the directionality of the input shock motion. The problems encountered with increasing the level of the shock are that there are non-linear displacements in the fire control such as: glass to glass contact, brittle fractures and separation of bounded joints. Another problem with increasing the magnitude of the shock is "stiction", which is a combination of sticking and friction. Here, components, which are locked in place below one level of shock, do not respond until a shock of a significantly increased level breaks them free to respond. This type of unrealistic failure could be induced in laboratory testing by increasing the shock level, and yet, may never occur because of field firings. The other general category, directionality, includes various problems such as: non-symmetrical structures where the fire control instrument being loaded in one direction has a fully supported component but being loaded in an opposite direction has a different structural support path with different conditions for failure.

One method of approach, which could adequately test the primary structure and would not be a realistic test for the non-linear effects mentioned, is to vary the input shock level by a factor based on physical properties of the primary structure's material. For example, the ratio of the tensile allowable to the fatigue allowable could be used. Thus, increasing the shock input level by this ratio would produce the following positive effects: if the stresses in the primary structure were above the fatigue allowable, the system would fail; if the stresses in the fire control instrument were below the fatigue allowable, these stresses would be increased but they would not be increased to the extent that they would exceed the tensile allowable and therefore, the system would not fail. It is, also, possible that unrealistic laboratory failures would be encountered in some of the non-linear systems such as de-bonding, or prisms coming in contact, or glass breaking.

The above approach is simple and negates the requirement of stress coating or strain gaging the fire control to determine what the stress levels are. It is also a test

that is simple to conduct. It would be a "go/no-go" type of a test for the primary structure. If the fire control survives this increased stress test specification, it is a good indication that it would survive for the life of the weapon. If it did not survive this increased specification, it would then have to be determined whether the failure was due to primary structure or due to a non-linear component. If it was due to primary structure this would indicate that the fire control is questionable as far as surviving the fatigue stresses induced by many firings. If it failed due to any of the non-linear brittle fractures or de-bonding, or glass to glass contact. The chances are that these would not be failures occurring in the field due to many test firings. The area of concern is whether the failures produced in the laboratory would or would not be encountered due to many test firings.

Section 6

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

An overall assessment of the program described in this report leads to some interesting observations regarding the laboratory shock testing of fire control instruments. Most important is the observation that for a broad range of instruments, laboratory tests can be developed which are a very satisfactory simulation of the field firing shock environment if a test validation procedure is conducted. In each case studied, the tests selected can be performed on commercial shock machines using elastic impact pads, and require no exotic preparations or procedures. Generally, the finding is that instruments should be tested in their used configuration, that is, a telescope and telescope mount should be tested together. The relative fits and mechanical impedances of instrument combinations significantly effect their response to shock inputs. For the most realistic simulation of the field environment, instruments should be laboratory tested in their used configuration, in order that the effects of this combination are included in the system's laboratory response.

Another interesting finding in this program is that for many fire control instruments, which are typically unbalanced and unsymmetrical, significant responses are generated in directions perpendicular to the axis of the shock input. A related finding is that positive and negative responses of the instruments are often the same, both in the field and in the laboratory, even though laboratory inputs are unidirectional. The significance of this is that in order to obtain good simulation, it may not be necessary to test in both directions of all three instrument axes as is typically required in test specifications. A test validation procedure such as those conducted in this program, must be performed in order to determine which directions or axes need not be included in the laboratory test. Often, such simplifications are possible, and when they are, the quality assurance testing process can be not only more realistic, but more economical. The economies arise from simpler test fixtures and reduced labor costs in that less handling is required simultaneously, resulting in further savings. While each situation would be different, the potential exists for significant savings on in-process shock testing throughout the production phase of a fire control system.

A broad range of instruments were tested in this program to determine if there were characteristics peculiar to certain classes of instruments which could influence the shock test procedures. The M53 Mortar Sightunit, the M102 Artillery System and the M119 Sheridan Telescope are typical examples of the fire control instruments on three types of weapon systems. Each one exhibits a degree of looseness or inelasticity due to gearing clearances, preload springs, flexible connections, hinge joints, and a variety of similar features. When subjected to dynamic loading, these

instruments tend to rattle and develop impacting of various components, resulting in high frequency vibrations, with positive and negative responses approximately equal. This results in making the response of the instruments relatively independent of the direction in which a shock is applied. Consequently, applying a shock in both directions of a given axis for such instruments may be unnecessary and leads to simplification in the test procedures.

The M551 Sheridan's M44 Periscope, on the other hand, does not exhibit any particular looseness and is a tight elastic system. This instrument is more sensitive to the direction of shock input, positive and negative responses frequently not being the same for a given input. In systems of this type, it is likely that shocks must be applied in both directions of an axis in order to achieve good simulation.

The shock pulse durations recommended for the various instruments tested in this program are shorter than those appearing in general environmental test specifications. The high intensity shock test of MIL-STD-810C calls for a 6 millisecond shock pulse, while the recommended shock pulses for the fire control ranged from 3 milliseconds down to 0.5 millisecond. Generally, it is concluded that the firing shock environment for fire control instruments is characterized by short shock pulse durations of 3 milliseconds or less.

The approach of analyzing shock data in the form of primary (+) and (−) shock spectra has proven to be quite useful. Previously, data has been analyzed in the form of maximax shock spectra, wherein any information on the directional characteristics of the shock environment is lost. These characteristics can be important and when it is determined that an instrument is not sensitive to the direction of shock applied along a given axis, it leads directly to a simplification of the test procedure. The field firing data analyzed in this program generally shows that positive and negative responses are the same, indicating vibratory motion. This characteristic is probably typical of the shock environment for most fire control instruments. Whether or not positive and negative responses are equal in the laboratory for a given shock input, is largely dependent on the structural characteristics of the instrument.

Recommendations

1. The recommended shock tests summarized in Table IV should be implemented into the specification test requirements for the fire control instruments on the M29 Mortar, the M102 Howitzer and the M551 Sheridan Vehicle.

Table IV. Recommended Shock Tests.

Weapon System	Fire Control Instrument	Axis	Recommended Half-Sine Shock Pulse	
			(g's)	(Milliseconds)
M29 Mortar	M53 Sightunit	Vertical (45° to the dovetail axis in both directions)	250	1.
		Transverse (pulling the dovetail away from the sight)	325	0.5
M102 Howitzer	Direct Fire Control	Vertical (up) Longitudinal (forward)	175	2.
		Transverse (outward)	75	2.
	Indirect Fire Control	Vertical (up) Longitudinal (forward)	50	2.
		Longitudinal (aft)	50	3.
M551 Sheridan	M127 Telescope and M149 Mount	Vertical (down) Longitudinal (aft) Transverse (right to left)	150	1.
	XM44 Periscope	Vertical (up and down) Longitudinal (aft) Transverse (right to left)	50	3.

Each instrument is to be shocked a total of 18 times, 6 times in each of the above directions.

2. The test validation procedure used here should be carried out as a follow-on activity to obtain firing shock measurements for new fire control instruments.

3. Firing shock data should be analyzed in terms of primary (+) and (−) shock spectra in order to investigate the directional characteristics of the environment.

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